Table 5.9b Example of characterization of a Ground Parameter Set for a given zone

<table>
<tr><td colspan="3" rowspan="2">Ground Parameter Set number</td><td colspan="2" rowspan="2">26</td><td colspan="4">Zones in which the GPS is present in Alignment Alternative AV</td><td colspan="2">T5_16, T5_20</td></tr>
<tr><td colspan="4">Zones in which the GPS is present in Alignment Alternative I-5</td><td colspan="2">T2_14, T2_16, T4_6</td></tr>
<tr><td colspan="5">BEHAVIORAL CATEGORIES</td><td colspan="2">POTENTIAL INSTABILITY CONDITIONS</td><td colspan="2">POTENTIAL PROBLEMATIC WATER INFLOW</td><td colspan="2">POSSIBLE PRESENCE OF GAS</td></tr>
<tr><td>a/b</td><td>c</td><td>d</td><td>e/f</td><td>Fault</td><td>Instability</td><td>No instability</td><td>Water inflow</td><td>No water inflow</td><td>Gas detected</td><td>No gas detected</td></tr>
<tr><td></td><td>90%</td><td>10%</td><td></td><td></td><td>1%</td><td>99%</td><td>1%</td><td>99%</td><td>10%</td><td>90%</td></tr>
<tr><td colspan="5">Notes</td><td colspan="2">Notes</td><td colspan="2">Notes</td><td colspan="2">Notes</td></tr>
<tr><td colspan="5">In the zones characterized by the GPS 26, DAT assigns to each unit length a behavioral category that is determined with the Monte Carlo method assuming a probabilistic distribution of 90% of "c" group and a 10% of "d" group.</td><td colspan="2">In the same zones, the presence of instability conditions has a probabilistic distribution of 1% of occurrence, and 99% of no occurrence</td><td colspan="2">The presence of problematic water inflows has a probabilistic distribution of 1% of occurrence, and 99% of no occurrence</td><td colspan="2">In the same manner, the presence of gas has a probabilistic distribution of 10% of occurrence, and 90% of no occurrence</td></tr>
</table>

The Ground Parameter Set n°26 is shown with its characteristics in Table 5.9b; the meaning of the given probabilities is expressed in the last-row notes. For each unit length (whose value gives the distance between two successive parameters typically 10 m), the Monte Carlo method is applied to determine the state of each parameter following the distribution of probabilities defined in the corresponding Ground Parameter Set. With reference to the same Ground Parameter Set n°26, shown as an example, it can be pointed out that each unit segment can be assigned a "c" or a "d" behavioral category following respective probabilities of 90% and 10%. In the same way, instability or no instability can be assigned with a 1%/99% ratio, as well as water inflow or no water inflow and gas detected and no gas detected with their relative probabilities. This leads to the fact that each unit segment characterized with a Ground Parameter Set n°26 may be assigned to a combination of parameters that is different in every simulation run. (See Table 5.9c):

Table 5.9c Example of the combinations of Behavioral category, Instability conditions, Problematic water inflow and Presence of Gas that can be assigned to a unit segment characterized by a defined Ground Parameter Set (in this example, set n° 26).

GROUND PARAMETER SET N° 26			
BEHAVIORAL CATEGORIES	**POTENTIAL INSTABILITY CONDITIONS**	**POTENTIAL PROBLEMATIC WATER INFLOW**	**POSSIBLE PRESENCE OF GAS**
c (90%)	Instability (1%)	Water inflow (1%)	Gas detected (10%)
			No gas detected (90%)
		No water inflow (99%)	Gas detected (10%)
			No gas detected (90%)
	No instability (99%)	Water inflow (1%)	Gas detected (10%)
			No gas detected (90%)
		No water inflow (99%)	Gas detected (10%)
			No gas detected (90%)
d (10%)	Instability (1%)	Water inflow (1%)	Gas detected (10%)
			No gas detected (90%)
		No water inflow (99%)	Gas detected (10%)
			No gas detected (90%)
	No instability (99%)	Water inflow (1%)	Gas detected (10%)
			No gas detected (90%)
		No water inflow (99%)	Gas detected (10%)
			No gas detected (90%)

As explained in Section 5.1, it is not possible to show the detailed zoning of each segment, as it varies in each simulation run and its single run report would not bring any further useful information. The zoning of both the Alignment Alternatives is thus given in Tables 5.10 to 5.17, showing both the probabilistic positioning of zones and the probabilistic assignment of the parameters by means of the Ground Parameter Set zoning. In Tables 5.18 and 5.19 the zoning of the parameter "Anomalous abrasivity" is shown. The zonings with little error are valid for both max grade options 2.5% and 3.5%.

Finally, it should be pointed out that the estimation of the probability of occurrence of adverse geologic conditions is partly based on engineering judgement and past experiences gained from tunneling in similar geologic environments, in addition to maximizing the usage of the available information. This approach is appropriate considering the limited quality and the extent of the available geologic knowledge about the specific area of interest, as mentioned earlier in Section 1.2.1. In the future when additional new information (from direct investigations and from records of past tunneling experiences in the project region) becomes available one can use the new information to check the adequacy of currently assumed figures and to re-calibrate the occurrence assumptions of adverse conditions, thus arriving at a more objective model.

Table 5.10 Alignment Alternative I-5 - Subdivision in homogeneous zones and Ground Parameter Set of each zone (1 of 4).

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9	Zone 10	Zone 11	Zone 12	Zone 13	Zone 14	Zone 15	Zone 16
Name	T1_0	T1_1	T1_2	T1_3 Pleito	T1_4	T1_5	T1_6	T1_7	T1_8 f	T1_9	T1_10 f	T1_11	T1_12 f	T1_13	T1_14 f	T1_15
Generation mode	1	1	2	1	1	1	1	2	1	2	1	2	1	2	1	2
Min length	57000	150	--	100	50	700	400	--	50	--	50	--	50	--	50	--
Mode length	57000	200	--	200	100	800	500	--	100	--	100	--	100	--	100	--
Max length	57000	250	--	300	150	900	600	--	150	--	150	--	150	--	150	--
Prob. Min length	0	0.1	--	0.1	0.1	0.1	0	--	0	--	0	--	0	--	0	--
Prob. Max length	0	0.1	--	0.1	0.1	0.1	0	--	0	--	0	--	0	--	0	--
Min end position	--	--	57550	--	--	--	--	62300	--	62900	--	63800	--	64500	--	66700
Mode end position	57000	--	57600	--	--	--	--	62400	--	63000	--	63900	--	64600	--	66850
Max end position	--	--	57650	--	--	--	--	62500	--	63100	--	64000	--	64700	--	67000
Prob. Min position	--	--	0	--	--	--	--	0	--	0	--	0	--	0	--	0
Prob. Max pos	--	--	0	--	--	--	--	0	--	0	--	0	--	0	--	0
Ground parameter set	41	41	24	5	24	17	19	24	3	24	3	24	3	20	3	41

	Zone 17	Zone 18	Zone 19	Zone 20	Zone 21	Zone 22	Zone 23	Zone 24	Zone 25	Zone 26	Zone 27	Zone 28	Zone 29	Zone 30	Zone 31	Zone 32
Name	T1_16 Pastoria	T1_17	T1_18	T1_19 Garlock	T1_20	T1_21	T1_22	T1_23 S Andreas	T2_1	T2_2	T2_3 f	T2_4	T2_5 f	T2_6	T2_7 f	T2_8
Generation mode	1	2	1	1	1	2	2	2	1	2	1	2	1	2	1	2
Min length	200	--	150	600	150	--	--	--	50	--	25	--	25	--	25	--
Mode length	500	--	200	800	200	--	--	--	100	--	50	--	50	--	50	--
Max length	800	--	250	1000	250	--	--	--	150	--	75	--	75	--	75	--
Prob. Min length	0	--	0	0	0	--	--	--	0	--	0.5	--	0.5	--	0.5	--
Prob. Max length	0	--	0	0	0	--	--	--	0	--	0	--	0	--	0	--
Min end position	--	69500	--	--	--	75600	76700	86600	--	87800	--	90000	--	91800	--	93500
Mode end position	--	69650	--	--	--	75800	76800	86600	--	87900	--	90100	--	91900	--	93600
Max end position	--	69800	--	--	--	76000	76700	86600	--	88000	--	90200	--	92000	--	93700
Prob. Min position	--	0	--	--	--	0	0	0	--	0	--	0	--	0	--	0
Prob. Max pos	--	0	--	--	--	0	0	0	--	0	--	0	--	0	--	0
Ground parameter set	5	22	24	5	24	22	36	5	41	21	4	21	4	27	4	34

Table 5.11 Alignment Alternative I-5 - Subdivision in homogeneous zones and Ground Parameter Set of each zone (2 of 4)

	Zone 33	Zone 34	Zone 35	Zone 36	Zone 37	Zone 38	Zone 39	Zone 40	Zone 41	Zone 42	Zone 43	Zone 44	Zone 45	Zone 46	Zone 47	Zone 48
Name	T2_9 f	T2_10	T2_11 f	T2_12	T2_13 f	T2_14	T2_15 f	T2_16	T2_17 f	T2_18	T2_19	T2_20 f	T2_21	T2_22 f	T2_23	T3_1
Generation mode	1	2	1	2	1	2	1	2	1	2	2	1	2	1	2	1
Min length	25	--	25	--	25	--	25	--	25	--	--	25	--	25	--	1900
Mode length	50	--	50	--	50	--	50	--	50	--	--	50	--	50	--	2100
Max length	75	--	100	--	75	--	75	--	75	--	--	75	--	75	--	2300
Prob. Min length	0.5	--	0	--	0.5	--	0.5	--	0.5	--	--	0.5	--	0.5	--	0
Prob. Max length	0	--	0	--	0	--	0	--	0	--	--	0	--	0	--	0
Min end position	--	94500	--	97300	--	101200	--	103100	--	104350	106250	--	109750	--	120000	--
Mode end position	--	94600	--	97400	--	101300	--	103200	--	104550	106350	--	109850	--	120000	--
Max end position	--	94700	--	97500	--	101400	--	103300	--	104750	106450	--	109950	--	120000	--
Prob. Min position	--	0	--	0	--	0	--	0	--	0	0	--	0	--	0	--
Prob. Max pos	--	0	--	0	--	0	--	0	--	0	0	--	0	--	0	--
Ground parameter set	4	34	4	34	4	26	4	26	4	34	43	4	43	4	43	36

	Zone 49	Zone 50	Zone 51	Zone 52	Zone 53	Zone 54	Zone 55	Zone 56	Zone 57	Zone 58	Zone 59	Zone 60	Zone 61	Zone 62	Zone 63	
Name	T3_2	T3_3 f	T3_4	T3_5 f	T3_6	T3_7 f	T3_8	T4_1	T4_2	T4_3 f	T4_4	T4_5 f	T4_6	T4_7 f	T4_8	
Generation mode	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	
Min length	--	25	--	100	--	25	--	50	--	25	--	25	--	25	--	
Mode length	--	50	--	150	--	50	--	100	--	50	--	50	--	50	--	
Max length	--	75	--	250	--	75	--	150	--	75	--	75	--	75	--	
Prob. Min length	--	0.5	--	0	--	0.5	--	0	--	0.5	--	0.5	--	0.5	--	
Prob. Max length	--	0	--	0	--	0	--	0	--	0	--	0	--	0	--	
Min end position	123200	--	124100	--	125500	--	132000	--	134200	--	134600	--	135200	--	200000	
Mode end position	123300	--	124200	--	125600	--	132000	--	134300	--	134700	--	135300	--	200000	
Max end position	123400	--	124300	--	125700	--	132000	--	134400	--	134800	--	135400	--	200000	
Prob. Min position	0	--	0	--	0	--	0	--	0	--	0	--	0	--	0	
Prob. Max pos	0	--	0	--	0	--	0	--	0	--	0	--	0	--	0	
Ground parameter set	36	4	36	6	36	4	36	41	27	4	27	4	26	4	41	

Table 5.12 Alignment Alternative I-5 - Subdivision in homogeneous zones and Ground Parameter Set of each zone (3 of 4)

				BEHAVIORAL CATEGORIES					POTENTIAL INSTABILITY CONDITIONS		POTENTIAL PROBLEMATIC WATER INFLOW		POSSIBLE PRESENCE OF GAS		Ground Parameter Set
Zone number	Zone name	Mode start position	Mode end position	a/b	c	d	e/f	Fault	Instability	No instability	Water inflow	No water inflow	Gas detected	No gas detected	
Zone 1	T1_0	57000	57000	0%	0%	50%	50%	0%	1%	99%	0%	100%	0%	100%	41
Zone 2	T1_1	57000	57200	0%	0%	50%	50%	0%	1%	99%	0%	100%	0%	100%	41
Zone 3	T1_2	57200	57600	0%	90%	10%	0%	0%	1%	99%	1%	99%	0%	100%	24
Zone 4	T1_3 Pleito	57600	57800	0%	0%	0%	0%	100%	10%	90%	20%	80%	0%	100%	5
Zone 5	T1_4	57800	57900	0%	90%	10%	0%	0%	1%	99%	1%	99%	0%	100%	24
Zone 6	T1_5	57900	58700	90%	10%	0%	0%	0%	0%	100%	0%	100%	0%	100%	17
Zone 7	T1_6	58700	59200	90%	10%	0%	0%	0%	0%	100%	0%	100%	10%	90%	19
Zone 8	T1_7	59200	62400	0%	90%	10%	0%	0%	1%	99%	1%	99%	0%	100%	24
Zone 9	T1_8 f	62400	62500	0%	0%	0%	0%	100%	1%	99%	10%	90%	0%	100%	3
Zone 10	T1_9	62500	63000	0%	90%	10%	0%	0%	1%	99%	1%	99%	0%	100%	24
Zone 11	T1_10 f	63000	63100	0%	0%	0%	0%	100%	1%	99%	10%	90%	0%	100%	3
Zone 12	T1_11	63100	63900	0%	90%	10%	0%	0%	1%	99%	1%	99%	0%	100%	24
Zone 13	T1_12 f	63900	64000	0%	0%	0%	0%	100%	1%	99%	10%	90%	0%	100%	3
Zone 14	T1_13	64000	64600	10%	90%	0%	0%	0%	0%	100%	0%	100%	0%	100%	20
Zone 15	T1_14 f	64600	64700	0%	0%	0%	0%	100%	1%	99%	10%	90%	0%	100%	3
Zone 16	T1_15	64700	66850	0%	0%	50%	50%	0%	1%	99%	0%	100%	0%	100%	41
Zone 17	T1_16 Pastoria	66850	67350	0%	0%	0%	0%	100%	10%	90%	20%	80%	0%	100%	5
Zone 18	T1_17	67350	69650	50%	50%	0%	0%	0%	0%	100%	0%	100%	0%	100%	22
Zone 19	T1_18	69650	69850	0%	90%	10%	0%	0%	1%	99%	1%	99%	0%	100%	24
Zone 20	T1_19 Garlock	69850	70650	0%	0%	0%	0%	100%	10%	90%	20%	80%	0%	100%	5
Zone 21	T1_20	70650	70850	0%	90%	10%	0%	0%	1%	99%	1%	99%	0%	100%	24
Zone 22	T1_21	70850	75800	50%	50%	0%	0%	0%	0%	100%	0%	100%	0%	100%	22
Zone 23	T1_22	75800	76800	0%	0%	0%	0%	100%	10%	90%	20%	80%	0%	100%	5
Zone 24	T1_23 S Andreas	76800	86600	0%	0%	0%	0%	100%	10%	90%	20%	80%	0%	100%	5
Zone 25	T2_1	86600	86700	0%	0%	50%	50%	0%	1%	99%	0%	100%	0%	100%	41
Zone 26	T2_2	86700	87900	10%	90%	0%	0%	0%	0%	100%	0%	100%	10%	90%	21
Zone 27	T2_3 f	87900	87950	0%	0%	0%	0%	100%	1%	99%	10%	90%	10%	90%	4
Zone 28	T2_4	87950	90100	10%	90%	0%	0%	0%	0%	100%	0%	100%	10%	90%	21
Zone 29	T2_5 f	90100	90150	0%	0%	0%	0%	100%	1%	99%	10%	90%	10%	90%	4
Zone 30	T2_6	90150	91900	0%	90%	10%	0%	0%	1%	99%	0%	100%	10%	90%	27
Zone 31	T2_7 f	91900	91950	0%	0%	0%	0%	100%	1%	99%	10%	90%	10%	90%	4
Zone 32	T2_8	91950	93600	0%	50%	50%	0%	0%	1%	99%	1%	99%	10%	90%	34
Zone 33	T2_9 f	93600	93650	0%	0%	0%	0%	100%	1%	99%	10%	90%	10%	90%	4
Zone 34	T2_10	93650	94600	0%	50%	50%	0%	0%	1%	99%	1%	99%	10%	90%	34
Zone 35	T2_11 f	94600	94650	0%	0%	0%	0%	100%	1%	99%	10%	90%	10%	90%	4
Zone 36	T2_12	94650	97400	0%	50%	50%	0%	0%	1%	99%	1%	99%	10%	90%	34
Zone 37	T2_13 f	97400	97450	0%	0%	0%	0%	100%	1%	99%	10%	90%	10%	90%	4
Zone 38	T2_14	97450	101300	0%	90%	10%	0%	0%	1%	99%	1%	99%	10%	90%	26
Zone 39	T2_15 f	101300	101350	0%	0%	0%	0%	100%	1%	99%	10%	90%	10%	90%	4
Zone 40	T2_16	101350	103200	0%	90%	10%	0%	0%	1%	99%	1%	99%	10%	90%	26
Zone 41	T2_17 f	103200	103250	0%	0%	0%	0%	100%	1%	99%	10%	90%	10%	90%	4
Zone 42	T2_18	103250	104550	0%	50%	50%	0%	0%	1%	99%	1%	99%	10%	90%	34

Table 5.13 Alignment Alternative I-5 - Subdivision in homogeneous zones and Ground Parameter Set of each zone (4 of 4)

Zone number	Zone name	Mode start position	Mode end position	BEHAVIORAL CATEGORIES					POTENTIAL INSTABILITY CONDITIONS		POTENTIAL PROBLEMATIC WATER INFLOW		POSSIBLE PRESENCE OF GAS		Ground Parameter Set
				a/b	c	d	e/f	Fault	Instability	No instability	Water inflow	No water inflow	Gas detected	No gas detected	
Zone 43	T2_19	104550	106350	0%	0%	50%	50%	0%	1%	99%	0%	100%	10%	90%	43
Zone 44	T2_20 f	106350	106400	0%	0%	0%	0%	100%	1%	99%	10%	90%	10%	90%	4
Zone 45	T2_21	106400	109850	0%	0%	50%	50%	0%	1%	99%	0%	100%	10%	90%	43
Zone 46	T2_22 f	109850	109900	0%	0%	0%	0%	100%	1%	99%	10%	90%	10%	90%	4
Zone 47	T2_23	109900	120000	0%	0%	50%	50%	0%	1%	99%	0%	100%	10%	90%	43
Zone 48	T3_1	120000	122100	0%	0%	10%	90%	0%	1%	99%	1%	99%	0%	100%	36
Zone 49	T3_2	122100	123300	0%	0%	10%	90%	0%	1%	99%	1%	99%	0%	100%	36
Zone 50	T3_3 f	123300	123350	0%	0%	0%	0%	100%	1%	99%	10%	90%	10%	90%	4
Zone 51	T3_4	123350	124200	0%	0%	10%	90%	0%	1%	99%	1%	99%	0%	100%	36
Zone 52	T3_5 f	124200	124350	0%	0%	0%	0%	100%	10%	90%	20%	80%	20%	80%	6
Zone 53	T3_6	124350	125600	0%	0%	10%	90%	0%	1%	99%	1%	99%	0%	100%	36
Zone 54	T3_7 f	125600	125650	0%	0%	0%	0%	100%	1%	99%	10%	90%	10%	90%	4
Zone 55	T3_8	125650	132000	0%	0%	10%	90%	0%	1%	99%	1%	99%	0%	100%	36
Zone 56	T4_1	132000	132100	0%	0%	50%	50%	0%	1%	99%	0%	100%	0%	100%	41
Zone 57	T4_2	132100	134300	0%	90%	10%	0%	0%	1%	99%	0%	100%	10%	90%	27
Zone 58	T4_3 f	134300	134350	0%	0%	0%	0%	100%	1%	99%	10%	90%	10%	90%	4
Zone 59	T4_4	134350	134700	0%	90%	10%	0%	0%	1%	99%	0%	100%	10%	90%	27
Zone 60	T4_5 f	134700	134750	0%	0%	0%	0%	100%	1%	99%	10%	90%	10%	90%	4
Zone 61	T4_6	134750	135300	0%	90%	10%	0%	0%	1%	99%	1%	99%	10%	90%	26
Zone 62	T4_7 f	135300	135350	0%	0%	0%	0%	100%	1%	99%	10%	90%	10%	90%	4
Zone 63	T4_8	135350	200000	0%	0%	50%	50%	0%	1%	99%	0%	100%	0%	100%	41

Table 5.14 Alignment Alternative AV - Subdivision in homogeneous zones and Ground Parameter Set of each zone (1 of 4)

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9	Zone 10	Zone 11	Zone 12	Zone 13	Zone 14	Zone 15	Zone 16	Zone 17
Name	T1_0	T1_1	T1_2	T1_3 f	T1_4	T1_5	T1_6	T1_7	T1_8 Edison	T1_9	T1_10 Edison	T1_11	T2_1	T2_2 f	T2_3	T2_4 f	T2_5
Generation mode	1	2	2	1	2	2	1	2	1	2	2	2	1	1	2	1	2
Min length	35000	--	--	25	--	--	450	--	150	--	--	--	50	50	--	25	--
Mode length	35000	--	--	50	--	--	550	--	200	--	--	--	100	100	--	50	--
Max length	35000	--	--	75	--	--	650	--	250	--	--	--	150	150	--	75	--
Prob. Min length	0	--	--	0	--	--	0	--	0	--	--	--	0	0	--	0	--
Prob. Max length	0	--	--	0	--	--	0	--	0	--	--	--	0	0	--	0	--
Min end position	--	35050	35900	--	36500	37100	--	38300	--	39600	40400	45000	--	--	47950	--	50000
Mode end position	--	35100	36000	--	36600	37200	--	38400	--	39800	40600	45000	--	--	48050	--	50000
Max end position	--	35150	36100	--	36700	37300	--	38500	--	40000	40800	45000	--	--	48150	--	50000
Prob. Min position	--	0	0	--	0	0	--	0	--	0	0	0	--	--	0	--	0
Prob. Max pos	--	0	0	--	0	0	--	0	--	0	0	0	--	--	0	--	0
Ground parameter set	29	29	33	4	33	29	33	29	5	32	36	40	33	5	22	3	33

	Zone 18	Zone 19	Zone 20	Zone 21	Zone 22	Zone 23	Zone 24	Zone 25	Zone 26	Zone 27	Zone 28	Zone 29	Zone 30	Zone 31	Zone 32	Zone 33	Zone 34
Name	T3_1	T3_2	T3_3	T3_4	T3_5 f	T3_6	T3_7	T3_8	T3_9	T3_10 f	T3_11	T3_12 f	T3_13	T3_14	T3_15	T3_16 f	T3_17
Generation mode	1	2	1	1	1	1	2	1	2	1	2	1	2	2	2	1	2
Min length	50	--	25	4600	25	150	--	600	--	100	--	25	--	--	--	25	--
Mode length	75	--	50	4800	50	200	--	650	--	150	--	50	--	--	--	50	--
Max length	100	--	75	5000	75	250	--	700	--	200	--	75	--	--	--	75	--
Prob. Min length	0	--	0	0	0	0	--	0	--	0	--	0	--	--	--	0	--
Prob. Max length	0	--	0	0	0	0	--	0	--	0	--	0	--	--	--	0	--
Min end position	--	50800	--	--	--	--	58800	--	59900	--	61450	--	64500	66900	67700	--	69200
Mode end position	--	51000	--	--	--	--	59000	--	60100	--	61550	--	64600	67000	67800	--	69300
Max end position	--	51200	--	--	--	--	59200	--	60250	--	61650	--	64700	67100	67900	--	69400
Prob. Min position	--	0	--	--	--	--	0	--	0	--	0	--	0	0	0	--	0
Prob. Max pos	--	0	--	--	--	--	0	--	0	--	0	--	0	0	0	--	0
Ground parameter set	40	28	5	44	5	32	25	32	37	5	32	5	37	40	44	5	44

	Zone 35	Zone 36	Zone 37	Zone 38	Zone 39	Zone 40	Zone 41	Zone 42	Zone 43	Zone 44	Zone 45	Zone 46	Zone 47	Zone 48	Zone 49	Zone 50	Zone 51
Name	T3_18	T4_1	T4_2 f	T4_3	T4_4 Garlock	T4_5	T4_6 f	T4_7	T4_8 f	T4_9	T4_10	T4_11	T5_1	T5_2 f	T5_3	T5_4	T5_5 f
Generation mode	2	2	1	2	1	2	1	2	1	1	2	2	2	1	2	2	1
Min length	--	--	100	--	400	--	25	--	25	500	--	--	--	25	--	--	25
Mode length	--	--	150	--	500	--	50	--	50	600	--	--	--	50	--	--	50
Max length	--	--	200	--	600	--	75	--	75	700	--	--	--	75	--	--	75
Prob. Min length	--	--	0	--	0	--	0.5	--	0.5	0	--	--	--	0.5	--	--	0.5
Prob. Max length	--	--	0	--	0	--	0	--	0	0	--	--	--	0	--	--	0
Min end position	75000	77400	--	78750	--	82150	--	83400	--	--	84300	149400	150900	--	151650	152550	--
Mode end position	75000	77500	--	78850	--	82250	--	83500	--	--	84400	149400	151000	--	151750	152650	--
Max end position	75000	77600	--	78950	--	82350	--	83600	--	--	84500	149400	151100	--	151850	152750	--
Prob. Min position	0	0	--	0	--	0	--	0	--	--	0	0	0	--	0	0	--
Prob. Max pos	0	0	--	0	--	0	--	0	--	--	0	0	0	--	0	0	--
Ground parameter set	40	44	5	36	5	40	3	17	3	17	22	48	17	3	22	17	3

Table 5.15 Alignment Alternative AV - Subdivision in homogeneous zones and Ground Parameter Set of each zone (2 of 4)

	Zone 52	Zone 53	Zone 54	Zone 55	Zone 56	Zone 57	Zone 58	Zone 59	Zone 60	Zone 61	Zone 62	Zone 63	Zone 64	Zone 65	Zone 66	Zone 67	Zone 68
Name	T5_6	T5_7	T5_8	T5_9 f	T5_10	T5_11	T5_12	T5_13 f	T5_14	T5_15 f	T5_16	T5_17 f	T5_18	T5_19 f	T5_20	T6_1	T6_2 S. Gabriel
Generation mode	1	2	2	1	2	1	2	1	2	1	2	1	2	1	2	2	1
Min length	1100	--	--	25	--	600	--	100	--	100	--	25	--	25	--	--	100
Mode length	1200	--	--	50	--	700	--	150	--	150	--	50	--	50	--	--	150
Max length	1300	--	--	75	--	800	--	200	--	200	--	75	--	75	--	--	200
Prob. Min length	0	--	--	0.5	--	0	--	0	--	0	--	0.5	--	0.5	--	--	0
Prob. Max length	0	--	--	0	--	0	--	0	--	0	--	0	--	0	--	--	0
Min end position	--	155400	156150	--	156650	--	159050	--	161350	--	163900	--	164900	--	176800	177700	--
Mode end position	--	155500	156250	--	156750	--	159150	--	161450	--	164000	--	165000	--	176800	177800	--
Max end position	--	155600	156350	--	156850	--	159250	--	161550	--	164100	--	165100	--	176800	177900	--
Prob. Min position	--	0	0	--	0	--	0	--	0	--	0	--	0	--	0	0	--
Prob. Max pos	--	0	0	--	0	--	0	--	0	--	0	--	0	--	0	0	--
Ground parameter set	17	23	28	4	28	23	21	6	40	6	26	4	34	4	26	48	6

	Zone 69	Zone 70	Zone 71	Zone 72	Zone 73	Zone 74	Zone 75	Zone 76	Zone 77	Zone 78	Zone 79	Zone 80	Zone 81	Zone 82	Zone 83	Zone 84	
Name	T6_3	T6_4 S. Gabriel	T6_5	T6_6 S. Gabriel	T6_7	T6_8	T7_1	T7_2	T7_3 f	T7_4	T7_5	T7_6	T7_7 S. Susana	T7_8	T7_9 S. Susana	T7_10	
Generation mode	2	1	2	1	2	2	2	2	1	2	1	2	1	2	2	2	
Min length	--	100	--	100	--	--	--	--	25	--	200	--	50	--	--	--	
Mode length	--	150	--	150	--	--	--	--	50	--	300	--	100	--	--	--	
Max length	--	200	--	200	--	--	--	--	75	--	400	--	150	--	--	--	
Prob. Min length	--	0	--	0	--	--	--	--	0.5	--	0	--	0	--	--	--	
Prob. Max length	--	0	--	0	--	--	--	--	0	--	0	--	0	--	--	--	
Min end position	178000	--	178650	--	178900	180000	180250	180900	--	182000	--	183400	--	183900	184100	200000	
Mode end position	178050	--	178700	--	179200	180000	180350	181000	--	182600	--	183500	--	184050	184200	200000	
Max end position	178100	--	178750	--	179300	180000	180450	181100	--	183200	--	183800	--	184150	184400	200000	
Prob. Min position	0	--	0	--	0	0	0	0	--	0	--	0	--	0	0	0	
Prob. Max pos	0	--	0	--	0	0	0	0	--	0	--	0	--	0	0	0	
Ground parameter set	48	6	48	6	48	48	43	21	4	21	43	43	6	38	6	42	

Table 5.16 Alignment Alternative AV- Subdivision in homogeneous zones and Ground Parameter Set of each zone (3 of 4)

				BEHAVIORAL CATEGORIES					POTENTIAL INSTABILITY CONDITIONS		POTENTIAL PROBLEMATIC WATER INFLOW		POSSIBLE PRESENCE OF GAS		Ground Parameter Set
Zone number	Zone name	Mode start position	Mode end position	a/b	c	d	e/f	Fault	Instability	No instability	Water inflow	No water inflow	Gas detected	No gas detected	
T1_0	Zone 1	35000	35000	0%	10%	90%	0%	0%	1%	99%	0%	100%	0%	100%	29
T1_1	Zone 2	35000	35100	0%	10%	90%	0%	0%	1%	99%	0%	100%	0%	100%	29
T1_2	Zone 3	35100	36000	0%	50%	50%	0%	0%	1%	99%	0%	100%	0%	100%	33
T1_3 f	Zone 4	36000	36050	0%	0%	0%	0%	100%	5%	95%	10%	90%	10%	90%	4
T1_4	Zone 5	36050	36600	0%	50%	50%	0%	0%	1%	99%	0%	100%	0%	100%	33
T1_5	Zone 6	36600	37200	0%	10%	90%	0%	0%	1%	99%	0%	100%	0%	100%	29
T1_6	Zone 7	37200	37750	0%	50%	50%	0%	0%	1%	99%	0%	100%	0%	100%	33
T1_7	Zone 8	37750	38400	0%	10%	90%	0%	0%	1%	99%	0%	100%	0%	100%	29
T1_8 Edison	Zone 9	38400	38600	0%	0%	0%	0%	100%	10%	90%	20%	80%	0%	100%	5
T1_9	Zone 10	38600	39800	0%	50%	50%	0%	0%	1%	99%	1%	99%	0%	100%	32
T1_10 Edison	Zone 11	39800	40600	0%	0%	10%	90%	0%	1%	99%	1%	99%	0%	100%	36
T1_11	Zone 12	40600	45000	0%	0%	50%	50%	0%	1%	99%	1%	99%	0%	100%	40
T2_1	Zone 13	45000	45100	0%	50%	50%	0%	0%	1%	99%	0%	100%	0%	100%	33
T2_2 f	Zone 14	45100	45200	0%	0%	0%	0%	100%	10%	90%	20%	80%	0%	100%	5
T2_3	Zone 15	45200	48050	50%	50%	0%	0%	0%	0%	100%	0%	100%	0%	100%	22
T2_4 f	Zone 16	48050	48100	0%	0%	0%	0%	100%	5%	95%	10%	90%	0%	100%	3
T2_5	Zone 17	48100	50000	0%	50%	50%	0%	0%	1%	99%	0%	100%	0%	100%	33
T3_1	Zone 18	50000	50075	0%	0%	50%	50%	0%	1%	99%	1%	99%	0%	100%	40
T3_2	Zone 19	50075	51000	0%	10%	90%	0%	0%	1%	99%	1%	99%	0%	100%	28
T3_3	Zone 20	51000	51050	0%	0%	0%	0%	100%	10%	90%	20%	80%	0%	100%	5
T3_4	Zone 21	51050	55850	0%	0%	90%	10%	0%	1%	99%	1%	99%	0%	100%	44
T3_5 f	Zone 22	55850	55900	0%	0%	0%	0%	100%	10%	90%	20%	80%	0%	100%	5
T3_6	Zone 23	55900	56100	0%	50%	50%	0%	0%	1%	99%	1%	99%	0%	100%	32
T3_7	Zone 24	56100	59000	0%	90%	10%	0%	0%	1%	99%	0%	100%	0%	100%	25
T3_8	Zone 25	59000	59650	0%	50%	50%	0%	0%	1%	99%	1%	99%	0%	100%	32
T3_9	Zone 26	59650	60100	0%	0%	10%	90%	0%	1%	99%	0%	100%	0%	100%	37
T3_10 f	Zone 27	60100	60250	0%	0%	0%	0%	100%	10%	90%	20%	80%	0%	100%	5
T3_11	Zone 28	60250	61550	0%	50%	50%	0%	0%	1%	99%	1%	99%	0%	100%	32
T3_12 f	Zone 29	61550	61600	0%	0%	0%	0%	100%	10%	90%	20%	80%	0%	100%	5
T3_13	Zone 30	61600	64600	0%	0%	10%	90%	0%	1%	99%	0%	100%	0%	100%	37
T3_14	Zone 31	64600	67000	0%	0%	50%	50%	0%	1%	99%	1%	99%	0%	100%	40
T3_15	Zone 32	67000	67800	0%	0%	90%	10%	0%	1%	99%	1%	99%	0%	100%	44
T3_16 f	Zone 33	67800	67850	0%	0%	0%	0%	100%	10%	90%	20%	80%	0%	100%	5
T3_17	Zone 34	67850	69300	0%	0%	90%	10%	0%	1%	99%	1%	99%	0%	100%	44
T3_18	Zone 35	69300	75000	0%	0%	50%	50%	0%	1%	99%	1%	99%	0%	100%	40
T4_1	Zone 36	75000	77500	0%	0%	90%	10%	0%	1%	99%	1%	99%	0%	100%	44
T4_2 f	Zone 37	77500	77650	0%	0%	0%	0%	100%	10%	90%	20%	80%	0%	100%	5
T4_3	Zone 38	77650	78850	0%	0%	10%	90%	0%	1%	99%	1%	99%	0%	100%	36
T4_4 Garlock	Zone 39	78850	79350	0%	0%	0%	0%	100%	10%	90%	20%	80%	0%	100%	5
T4_5	Zone 40	79350	82250	0%	0%	50%	50%	0%	1%	99%	1%	99%	0%	100%	40
T4_6 f	Zone 41	82250	82300	0%	0%	0%	0%	100%	5%	95%	10%	90%	0%	100%	3
T4_7	Zone 42	82300	83500	90%	10%	0%	0%	0%	0%	100%	0%	100%	0%	100%	17

Table 5.17 Alignment Alternative AV- Subdivision in homogeneous zones and Ground Parameter Set of each zone (4 of 4)

				BEHAVIORAL CATEGORIES					POTENTIAL INSTABILITY CONDITIONS		POTENTIAL PROBLEMATIC WATER INFLOW		POSSIBLE PRESENCE OF GAS		Ground Parameter Set
Zone number	Zone name	Mode start position	Mode end position	a/b	c	d	e/f	Fault	Instability	No instability	Water inflow	No water inflow	Gas detected	No gas detected	
T4_8 f	Zone 43	83500	83550	0%	0%	0%	0%	100%	5%	95%	10%	90%	0%	100%	3
T4_9	Zone 44	83550	84150	90%	10%	0%	0%	0%	0%	100%	0%	100%	0%	100%	17
T4_10	Zone 45	84150	84400	50%	50%	0%	0%	0%	0%	100%	0%	100%	0%	100%	22
T4_11	Zone 46	84400	149400	0%	0%	50%	50%	0%	1%	99%	1%	99%	10%	90%	48
T5_1	Zone 47	149400	151000	90%	10%	0%	0%	0%	0%	100%	0%	100%	0%	100%	17
T5_2 f	Zone 48	151000	151050	0%	0%	0%	0%	100%	5%	95%	10%	90%	0%	100%	3
T5_3	Zone 49	151050	151750	50%	50%	0%	0%	0%	0%	100%	0%	100%	0%	100%	22
T5_4	Zone 50	151750	152650	90%	10%	0%	0%	0%	0%	100%	0%	100%	0%	100%	17
T5_5 f	Zone 51	152650	152700	0%	0%	0%	0%	100%	5%	95%	10%	90%	0%	100%	3
T5_6	Zone 52	152700	153900	90%	10%	0%	0%	0%	0%	100%	0%	100%	0%	100%	17
T5_7	Zone 53	153900	155500	50%	50%	0%	0%	0%	0%	100%	0%	100%	10%	90%	23
T5_8	Zone 54	155500	156250	0%	10%	90%	0%	0%	1%	99%	1%	99%	0%	100%	28
T5_9 f	Zone 55	156250	156300	0%	0%	0%	0%	100%	5%	95%	10%	90%	10%	90%	4
T5_10	Zone 56	156300	156750	0%	10%	90%	0%	0%	1%	99%	1%	99%	0%	100%	28
T5_11	Zone 57	156750	157450	50%	50%	0%	0%	0%	0%	100%	0%	100%	10%	90%	23
T5_12	Zone 58	157450	159150	10%	90%	0%	0%	0%	0%	100%	0%	100%	10%	90%	21
T5_13 f	Zone 59	159150	159300	0%	0%	0%	0%	100%	10%	90%	20%	80%	20%	80%	6
T5_14	Zone 60	159300	161450	0%	0%	50%	50%	0%	1%	99%	1%	99%	0%	100%	40
T5_15 f	Zone 61	161450	161600	0%	0%	0%	0%	100%	10%	90%	20%	80%	20%	80%	6
T5_16	Zone 62	161600	164000	0%	90%	10%	0%	0%	1%	99%	1%	99%	10%	90%	26
T5_17 f	Zone 63	164000	164050	0%	0%	0%	0%	100%	5%	95%	10%	90%	10%	90%	4
T5_18	Zone 64	164050	165000	0%	50%	50%	0%	0%	1%	99%	1%	99%	10%	90%	34
T5_19 f	Zone 65	165000	165050	0%	0%	0%	0%	100%	5%	95%	10%	90%	10%	90%	4
T5_20	Zone 66	165050	176800	0%	90%	10%	0%	0%	1%	99%	1%	99%	10%	90%	26
T6_1	Zone 67	176800	177800	0%	0%	50%	50%	0%	1%	99%	1%	99%	10%	90%	48
T6_2 S. Gabrie	Zone 68	177800	177950	0%	0%	0%	0%	100%	10%	90%	20%	80%	20%	80%	6
T6_3	Zone 69	177950	178050	0%	0%	50%	50%	0%	1%	99%	1%	99%	10%	90%	48
T6_4 S. Gabrie	Zone 70	178050	178200	0%	0%	0%	0%	100%	10%	90%	20%	80%	20%	80%	6
T6_5	Zone 71	178200	178700	0%	0%	50%	50%	0%	1%	99%	1%	99%	10%	90%	48
T6_6 S. Gabrie	Zone 72	178700	178850	0%	0%	0%	0%	100%	10%	90%	20%	80%	20%	80%	6
T6_7	Zone 73	178850	179200	0%	0%	50%	50%	0%	1%	99%	1%	99%	10%	90%	48
T6_8	Zone 74	179200	180000	0%	0%	50%	50%	0%	1%	99%	1%	99%	10%	90%	48
T7_1	Zone 75	180000	180350	0%	0%	50%	50%	0%	1%	99%	0%	100%	10%	90%	43
T7_2	Zone 76	180350	181000	10%	90%	0%	0%	0%	0%	100%	0%	100%	10%	90%	21
T7_3 f	Zone 77	181000	181050	0%	0%	0%	0%	100%	5%	95%	10%	90%	10%	90%	4
T7_4	Zone 78	181050	182600	10%	90%	0%	0%	0%	0%	100%	0%	100%	10%	90%	21
T7_5	Zone 79	182600	182900	0%	0%	50%	50%	0%	1%	99%	0%	100%	10%	90%	43
T7_6	Zone 80	182900	183500	0%	0%	50%	50%	0%	1%	99%	0%	100%	10%	90%	43
T7_7 S. Susan	Zone 81	183500	183600	0%	0%	0%	0%	100%	10%	90%	20%	80%	20%	80%	6
T7_8	Zone 82	183600	184050	0%	0%	10%	90%	0%	1%	99%	1%	99%	10%	90%	38
T7_9 S. Susan	Zone 83	184050	184200	0%	0%	0%	0%	100%	10%	90%	20%	80%	20%	80%	6
T7_10	Zone 84	184200	200000	0%	0%	50%	50%	0%	1%	99%	1%	99%	10%	90%	42

Table 5.18 Alignment Alternative I-5 - Zoning of the parameter "Anomalous abrasivity"

Abrasive zone n°	Parameter State	Generation Mode	Min. End Position	Mode End Position	Max. End Position	Prob Min.	Prob Max.	Mean End Position
1	Non abrasive zone	Position	57000	57000	57000	0	0	57000
2	Non abrasive zone	Position	57000	57100	57200	0.1	0.1	57000
3	Abrasive zone	Position	62100	62100	62300	0.1	0.1	62100
4	Non abrasive zone	Position	64800	64900	65000	0.1	0.1	64900
5	Abrasive zone	Position	66700	66800	66900	0.1	0.1	66800
6	Non abrasive zone	Position	67100	67200	67300	0.1	0.1	67200
7	Abrasive zone	Position	68900	69000	69100	0.1	0.1	69000
8	Non abrasive zone	Position	70600	70700	70800	0.1	0.1	70700
9	Abrasive zone	Position	86400	86500	86600	0.1	0.1	86500
10	Non abrasive zone	Position	96200	96300	96400	0.1	0.1	96300
11	Abrasive zone	Position	100200	100300	100400	0.1	0.1	100300
12	Non abrasive zone	Position	101200	101300	101400	0.1	0.1	101300
13	Abrasive zone	Position	104500	104600	104700	0.1	0.1	104600
14	Non abrasive zone	Position	136200	136200	136200	0.1	0.1	136200

Table 5.19 Alignment Alternative AV - Zoning of the parameter "Anomalous abrasivity"

Abrasive zone n°	Parameter State	Generation Mode	Min. End Position	Mode End Position	Max. End Position	Prob Min.	Prob Max.	Mean End Position
1	Non abrasive zone	Position	35000	35000	35000	0	0	35000
2	Non abrasive zone	Position	38400	38500	38600	0.1	0.1	38500
3	Abrasive zone	Position	56300	56400	56500	0.1	0.1	56400
4	Non abrasive zone	Position	56500	56600	56700	0.1	0.1	56600
5	Abrasive zone	Position	57900	58000	58100	0.1	0.1	58000
6	Non abrasive zone	Position	58600	58700	58800	0.1	0.1	58700
7	Abrasive zone	Position	59200	59300	59400	0.1	0.1	59300
8	Non abrasive zone	Position	60500	60600	60700	0.1	0.1	60600
9	Abrasive zone	Position	63600	63700	63800	0.1	0.1	63700
10	Non abrasive zone	Position	65300	65400	65500	0.1	0.1	65400
11	Abrasive zone	Position	79100	79200	79300	0.1	0.1	79200
12	Non abrasive zone	Position	84300	84400	84500	0.1	0.1	84400
13	Abrasive zone	Position	155200	155300	155400	0.1	0.1	155300
14	Non abrasive zone	Position	184800	184800	184800	0.1	0.1	184800

5.2 Construction Related Input

The construction related input has been modeled using the following scheme:

a) The basic average advance rates and costs per linear meter of tunnel have been defined for each construction method as follows:
   - Tunnel excavated by 9.5m diameter TBM;
   - Service tunnel excavated by 5.0m diameter TBM;
   - Tunnel excavated by Earth Pressure Balanced Shield;
   - Tunnel excavated by conventional method such as Drill and Blast or NATM;
   - Shaft excavated by conventional methods;
   - Seismic chamber excavated by conventional methods;
   - Portal zone realization.

   For each Behavioral Category (a/b, c, d, e/f and Fault), the definition is with a probabilistic min-mode-max range.

   The advance rates for excavation by TBMs have been defined based on the Colorado School of Mines Model (Clark, 1987 and Howart, 1987). The Model represents a well-known boring-speed prediction method that calculates the penetration rate per revolution of the TBM cutterhead on the basis of the rock mass characteristics (like the uniaxial compression strength and the tensile strength of the rocks), the characteristics of the cutters and the layout of the cutters of the cutterhead, as well as the machine-specific data (like maximum thrust on each cutter and rotation speed of the cutterhead). The Model gave a range of penetration rates for each rock formation. These predicated values together with the practical experiences gained from boring in similar geomechanical conditions, allowed for the definition of a realistic range of basic, average, advance rates for each Behavioral Category. The values of costs per meter for excavation by TBMs have been determined taking into account the various aspects involved such as the depreciation of the machine, assembly and disassembly as well as any transfer of the machine, the labor costs, the consumables including cutters, energy consumption, the segmental lining and/or grouting, etc. For the other excavation methods, costs and advance rates have been assumed mainly on the basis of relevant experiences gained from similar European projects, especially when no such data about U.S. projects are available.

b) In the DAT analysis, "Geo-event" related formulas have been defined in order to consider the influence of the occurrence of the unfavorable conditions on construction time and cost. Consequently, for each unit zone analyzed, if none of the unfavorable geo-events (like water inflow, anomalous abrasivity, etc.) is forecasted (or simulated by the geology module of DAT), the formulas defined for the corresponding, normal condition (in terms of the behavioral class and the associated construction method) will be used to calculate the time and cost for constructing the tunnel in this zone. If a problematic water inflow has been forecasted in a unit zone, the formulas defined for the specific type of geo-event will be used to determine the construction time and cost of this unit zone. The net influences of each unfavorable geo-event is the increase in the construction cost and the lowering of the advance rate, reflecting the impact of the specific interventions and/or downtime periods required to overcome the event.

c) If as a result of forecasting minor and major instability conditions there is an occurrence of an instability phenomena, an increasing law that considers the effect of successive and reiterated events has been adopted. In this manner, it is possible to take into account the effect of the socio-political-economic conditions that arise as a consequence of a repetitious accident. The cost of overcoming the problem is no longer stated in terms of time and cost but would depend on other aspects such as contracts, safety, social impact, etc.

5.2.1 Modeled activities and construction techniques

The construction of the various structures has been modeled in the DAT simulation as follows:

a) Main tunnels (diameter 9.5 m, single track twin tunnels) are mostly realized by means of fully mechanized excavation. Due to the anticipated geologic conditions and the related hazards, double shielded TBMs have been chosen in order to allow excavation and lining activities in medium to fair conditions. In poor conditions, excavation is slowed by the necessity of alternating lining installation and face advancing, while insufficient gripping conditions force the machine to act as a single shield TBM. While advance rates are significantly reduced, costs per meter are not affected to the same degree, which implies that the construction time of a tunnel in poor ground conditions may vary in a wider range than its final cost. As expressed previously, financial costs are not considered in this analysis.

b) In particular conditions, it is assumed the capability of the TBMs can be modified in order to exert a counter pressure to support the face during excavation. For those excavation methods, for which the construction schemes are referred to as EPB-Shields, the advance rates have a smaller range due to the very special features of the excavation technique itself and the particular field of application.

c) A service/safety tunnel (in this case, a single bore of 5.0 m in diameter) is required for those main, twin-bore tunnels longer than 6 miles (9.6 km) and this service/safety tunnel is assumed to be in a central position between the twin bores. Usually, the relatively small, service/safety tunnel will be constructed ahead of the main tunnel as the so-called pilot tunnel to probe the ground conditions and, hence, to reduce the geological uncertainties for the subsequent construction of the main tunnel. The excavation method assumed for the service/safety tunnels is the same as that assumed for the corresponding main tunnel, but with considerably higher advance rates when tunnelling in medium to fair conditions. However, the presence of very poor ground conditions will reduce the advance rates significantly since it has been assumed that the encounter of a critical zone will require the TBM excavating the service/safety tunnel to adopt wide inspection measures to exclude the possibility of having the machine blocked, while the TBMs for excavation of the main tunnel will subsequently use the information acquired.

d) Conventional techniques (NATM and others) have been applied to the construction of structures such as seismic chambers, shafts, portals and specific sectors of the main tunnels, where conditions and/or reduced lengths make the fully mechanized

d) Conventional techniques (NATM and others) have been applied to the construction of structures such as seismic chambers, shafts, portals and specific sectors of the main tunnels, where conditions and/or reduced lengths make the fully mechanized method uneconomic and/or unfeasible. In this last case, both advance rates and cost per meters may vary within a wider range than for the TBM methods. In very poor conditions it could be necessary to partialize the excavation section and/or realize wide consolidation interventions.

e) The by-pass to connect the parallel, twin bores of a main tunnel have not been considered in calculating the total construction time and cost of the main tunnel. However, it is important to define time and cost for constructing the bypasses in the global analysis. Besides their intended purpose, service/safety tunnels can help to keep the twin bores of a long, main tunnel at a distance which is approximately twice the separation distance between the twin bores of a relatively short main tunnel (i.e., less than 6 miles long), thus helping to avoid the stress-strain interferences between the twin bores of the main tunnel upon excavation. The only negative effect is that the number of bypasses under the triple-bore configuration will be twice that of the simple, twin-bore configuration.

5.2.2 Advance rates and costs per meter in "normal" conditions

The advance rates and costs per meter for the various technical classes and the various excavation techniques modeled are shown in Tables 5.20 to 5.29. Unit costs of some European tunnel projects are given in Appendix 3 for reference purpose. As mentioned previously, those values are applied directly in case no unfavorable events such as

water inflows, instabilities, anomalous abrasivity and presence of gas are detected, while they are employed in specific formulas if those "accidents" or "geo events" are encountered. The details of those aspects are shown in the following paragraphs.

Table 5.20 Distributions of advance rates for 9.5 m diameter TBMs

9.5 diameter TBMs: advance rates							
Parameter	**Parameter states**	**Min [m/d]**	**Mode [m/d]**	**Max [m/d]**	**Prob. min**	**Prob. max**	**Mean [m/d]**
Behavioral category	**a/b**	8.5	11.5	15	0.1	0.1	11.7
	c	11.5	14.6	18.7	0.1	0.1	15.0
	d	12	14.9	21.8	0.1	0.1	16.4
	e/f	8.2	9.5	11.9	0.1	0.1	9.9
	fault	8.2	9.5	11.9	0.1	0.1	9.9

Table 5.21 Distributions of excavation costs for 9.5 m diameter TBMs

9.5 diameter TBMs: costs per meter							
Parameter	**Parameter states**	**Min [US$/m]**	**Mode [US$/m]**	**Max [US$/m]**	**Prob. min**	**Prob. max**	**Mean [US$/m]**
	a/b	7850	8440	9180	0.1	0.1	8495

Behavioral category	a/b	7850	8440	9180	0.1	0.1	8495
	d	7260	7900	8470	0.1	0.1	7908
	e/f	8800	9500	10200	0.1	0.1	9500
	fault	8800	9500	10200	0.1	0.1	9500

Table 5.22 Distributions of advance rates for 5.0 m diameter TBMs

5.0 diameter TBMs: advance rates							
Parameter	Parameter states	Min [m/d]	Mode [m/d]	Max [m/d]	Prob. min	Prob. max	Mean [m/d]
Behavioral category	a/b	17	23	30	0.1	0.1	23.4
	c	23	29.2	37.4	0.1	0.1	29.9
	d	24	29.8	43.6	0.1	0.1	32.7
	e/f	12.5	13.9	16.3	0.1	0.1	14.3
	fault	12.5	13.9	16.3	0.1	0.1	14.3

Table 5.23 Distributions of excavation costs for 5.0 m diameter TBMs

5.0 diameter TBMs: costs per meter							
Parameter	Parameter states	Min [US$/m]	Mode [US$/m]	Max [US$/m]	Prob. min	Prob. max	Mean [US$/m]
	a/b	4690	4960	5350	0.1	0.1	5004
	c	4670	4850	5070	0.1	0.1	4864
	d	4430	4710	4940	0.1	0.1	4691
	e/f	5800	6100	6450	0.1	0.1	6118
	fault	5800	6100	6450	0.1	0.1	6118

Table 5.24 Distributions of advance rates for EPB machines

9.5 diameter EPBs: advance rates							
Parameter	Parameter states	Min [m/d]	Mode [m/d]	Max [m/d]	Prob. min	Prob. max	Mean [m/d]
Behavioral category	used mainly in e/f and fault	6	7.5	8	0.1	0.1	7.1

Table 5.25 Distributions of excavation costs for EPB machines

9.5 diameter EPBs: costs per meter							
Parameter	Parameter states	Min [US$/m]	Mode [US$/m]	Max [US$/m]	Prob. min	Prob. max	Mean [US$/m]
Behavioral category	used mainly in e/f and fault	10000	10500	11000	0.1	0.1	10500

Table 5.26 Distributions of advance rates for conventional methods excavation

Conventional methods excavation: advance rates							
Parameter	Parameter states	Min [m/d]	Mode [m/d]	Max [m/d]	Prob. min	Prob. max	Mean [m/d]
Behavioral category	a/b	5	5.5	6	0.1	0.1	5.5
	c	5	5.5	6	0.1	0.1	5.5
	d	2.5	2.75	3	0.1	0.1	2.8
	e/f	1.5	1.75	2	0.1	0.1	1.8
	fault	1.5	1.75	2	0.1	0.1	1.8

Table 5.27 Distributions of excavation costs for conventional methods excavation

Conventional methods excavation: costs per meter							
Parameter	Parameter states	Min [US$/m]	Mode [US$/m]	Max [US$/m]	Prob. min	Prob. max	Mean [US$/m]
Behavioral category	a/b	9000	9500	10000	0.1	0.1	9500
	c	9000	9500	10000	0.1	0.1	9500
	d	14000	14500	15000	0.1	0.1	14500
	e/f	20000	21000	22000	0.1	0.1	21000
	fault	20000	21000	22000	0.1	0.1	21000

Table 5.28 Distributions of advance rates for other conventional methods excavation

Other conventional methods excavation: advance rates						
Excavation activity	Min [m/d]	Mode [m/d]	Max [m/d]	Prob. min	Prob. max	Mean [m/d]
Shaft	2	3	4	0.1	0.1	3.0
Seismic chamber	1.75	2	2.5	0.1	0.1	2.1
Portals	4.5	6	7.5	0.1	0.1	6.0

Table 5.29 Distributions of excavation costs for other conventional methods excavation

Other conventional methods excavation: costs per meter						
Excavation activity	**Min [US$/m]**	**Mode [US$/m]**	**Max [US$/m]**	**Prob. min**	**Prob. max**	**Mean [US$/m]**
Shaft	13200	13400	13900	0.1	0.1	13510
Seismic chamber	45000	50000	55000	0.1	0.1	50000
Portals	12500	15000	17500	0.1	0.1	15000

5.2.3 Advance rates and costs per meter in instability zones

When unstable conditions are associated to a unit zone, two instability phenomena (parameter states) are simulated: Minor Instability Phenomenon and Major Instability Phenomenon.

In the first case, the simulation considers a minor event such as the temporary blockage of the cutterhead due to either detachments of rock wedges/blocks from the face or minor squeezing conditions. In the latter case, severe squeezing around the shield or face collapse is considered, resulting in important delays and a major intervention cost. In this latter case, the phenomenon has been considered as the result of coupled hydro-mechanical effects, and includes in itself the influence of the presence of water in terms of costs and delays.

In both cases, the costs and delays are not independent from previous instability phenomena, but follow an incremental law that amplifies the effect of successive and reiterated events.

- Time

Time necessary to overcome the unfavorable event unit zone is expressed with the following formula:

$$t_{\text{instability}} = (\text{delay\_time} + \frac{\text{unit\_length}}{\text{advance\_rate}}) \cdot F$$

where advance_rate = is the corresponding advance rate of the behavioral class, as seen in Tables 5.20 and 5.22.

delay_time = is the estimated duration of the intervention required to overcome the "accident", with different distributions in Minor and Major Instability Phenomena, as shown in the following table:

Table 5.30 Distribution of the delay time parameter

Instability Phenomena: delay times						
Instability Phenomenon	**Min [w-days]**	**Mode [w-days]**	**Max [w-days]**	**Prob. min**	**Prob. max**	**Mean [w-days]**
Minor (9.5 m TBM)	2.5	3.5	5	0.1	0.1	3.7
Major (9.5 m TBM)	7	15	30	0.1	0.1	17.6
Minor (5.0 m TBM)	1	1.5	2	0.1	0.1	1.5
Major (5.0 m TBM)	7	15	30	0.1	0.1	17.6

$F = F(A) = (1 + n \cdot A)$

n = number of repetition of the same "accident" in the same simulation

A = is an empirical factor characterizing the degree of impact of repeating accidents, whose value depends on the type of the Instability Phenomenon, as shown in the following table.

Table 5.31 Distribution of the values of the empirical factor A

Instability Phenomena: value of empirical factor A						
Instability Phenomenon	**Min**	**Mode**	**Max**	**Prob. min**	**Prob. max**	**Mean**
Minor	0.1	0.2	0.3	0.1	0.1	0.2
Major	0.25	0.5	0.8	0.1	0.1	0.5

As shown, the effect of reiterative events has been simulated with a relatively small amplitude in case of Minor Instability Phenomenon, while it may induce important and greater delays when Major Instability Phenomena occur.

- Cost

The total cost required to overcome the instability zone results from the association of two subcosts:

- a time dependent cost, consequence of the forced downtime and labor costs, based on an average cost per site stopped day whose average value is assumed to be $30,000 per day.
- direct additional cost of the remedial measures, which is a function of the particular type of intervention required to overcome the accident zone such as the protection of the crown level with forepoling, grouting with special materials as polyurethanes, or other ground treatments. These interventions have a higher cost in Major Instability Phenomena than in Minor ones, also the service tunnels require a lower intervention due to the minor diameter of the TBMs.

Both subcosts are subject to the factor that increases the amplitude of the event in case of reiterated events. The formula used to determine the cost of overcoming the unfavorable event zone is given:

$$cost_{instability} = (\$30{,}000 \cdot delay\_time + delay\_cost) \cdot F + unit\_length \cdot cost\_per\_meter$$

where cost_per_meter = is the corresponding cost per meter of the behavioral class, as shown in Tables 5.21 and 5.23.

delay_time = is the same parameter shown previously in the time equation.

delay_cost = is the estimated cost of the intervention, assumed on similar experiences, with different values in Minor and Major Instability Phenomena, as shown in the following table:

Table 5.32 Distribution of the delay cost parameter

Instability Phenomena: intervention costs	
Instability Phenomena	**Delay_cost [US$]**
Minor (9.5 m TBM)	100,000
Major (9.5 m TBM)	300,000
Minor (5.0 m TBM)	70,000
Major (5.0 m TBM)	200,000

$F = F(A) = (1 + n \cdot A)$ is the same parameter used previously in the time equation.

5.2.4 Advance rates and costs per meter in problematic water inflow zones

- *Time*

When severe water inflow zones are to be encountered, a "delay time" parameter is defined to account for the delay imposed by pumping out the water from the excavation face. The equation that expresses the time necessary to overcome a unit zone characterized by the water inflow event is given:

$$t_{water\ inflow} = delay\_time + \frac{unit\_length}{advance\_rate}$$

where the parameters are the same as those used to represent the instability case, except for the "delay_time" whose values are the following:

Table 5.33 Distribution of the values of the "delay_time" parameter characterizing severe water inflows.

Problematic water inflows: delay_time						
Water Inflow Phenomena	**Min [w-days]**	**Mode [w-days]**	**Max [w-days]**	**Prob. min**	**Prob. max**	**Mean [w-days]**
Severe water inflow	1	1.5	2	0.1	0.1	1.5

- Cost

The cost of overcoming the event has been modeled as time dependent, since it depends on the downtime period and on the energy consumption of the pumping system. The average cost per day is slightly higher than that of the production stop cost, because it includes the energy cost, i.e. $31,000 per day.

$$cost_{\text{water inflow}} = (\$31{,}000 \cdot delay\_time) + unit\_length \cdot cost\_per\_meter$$

5.2.5 Advance rates and costs per meter in gas-bearing zones

It is assumed gas detection devices will be employed during the excavation, thus avoiding unexpected gas ignitions. It is common to do this where there is risk of encountering gas pockets.

- Time

When gas bearing zones are to be encountered, a "delay time" parameter is used to account for the delay imposed by the necessity to de-gas the tunneling environment. The equation that expresses the time necessary to overcome a unit zone characterized by this event is given:

$$t_{\text{gas bearing}} = delay\_time + \frac{unit\_length}{advance\_rate}$$

where the parameters are the same as those used in the instability case, except for the "delay_time" whose values are the following:

Table 5.34 Distribution of the delay time parameter in presence of gas

Gas bearing zones: delay times						
Gas Phenomena	**Min [w-days]**	**Mode [w-days]**	**Max [w-days]**	**Prob. min**	**Prob. max**	**Mean [w-days]**
Present	1	1.5	2	0.1	0.1	1.5

- Cost

The cost of overcoming the gas bearing zone has been modeled as time dependent, as it depends both on the downtime period and on the energy consumption of the airing system. The average cost per day is slightly higher than the production stop cost to include the energy cost, i.e. $31,000 per day.

$$cost_{\text{gas detected}} = (\$31{,}000 \cdot delay\_time) + unit\_length \cdot cost\_per\_meter$$

5.2.6 Advance rates and costs per meter in anomalous-abrasivity zones

- Time

When anomalous-abrasivity zones are assigned, the equation that expresses the time necessary to overcome a unit zone characterized by this event considers a 10% increase of advance time due to more frequent change of the excavation tools, as given in the formula below:

$$t_{\text{anom.abrasivity}} = 1.10 \cdot \frac{\text{unit\_length}}{\text{advance\_rate}}$$

- Cost

In the same way, the cost necessary to overcome the same unit zone is also assumed to be 10% higher:

$$\text{cost}_{\text{anom.abrasivity}} = 1.10 \cdot \text{unit\_length} \cdot \text{cost\_per\_meter}$$

5.2.7 Other assumptions

All time related values are given in working days. Holidays, vacations and possible downtimes generated outside the construction process have not been taken into account.

Cost related values are given in US dollars and are inclusive of overhead and profit (10%) rates. All the conditions that could negatively affect the tunnel construction such as poor geomechanical conditions, "geo-events", etc. have been quantified in terms of their economic impact. Financial costs are not included in the DAT analysis.

A maximum number of simultaneous working sites has not been fixed. No limitations about the TBM's market have been considered, assuming generally a delivery time of approximately 12 months (range between 300 and 325 working days, with 6 working days per week and 26 working days per month) for the 9.5 m TBMs, and 8 months (range between 205 and 230 working days) for the 5.0 m TBMs. The on site assembly of each TBM will take approximately another two months (modal value 52, range between 45 and 60 working days). During the long period of TBM procurement and assembly, other working activities can be started or even completed, but each activity like excavation of shaft or advance a short tunnel by conventional method will also need to have a lead time of two months to prepare the site.

6. DAT SIMULATION RESULTS

6.1 Summary Description of the Pre-DAT-Simulation Analysis

With reference to the flowchart illustrating the process of risk analysis (see figure 1.2), the following preparatory tasks for the DAT simulations were accomplished:

- Definition of the design and construction-options in Section 3;
- Definition of input data to the Geological Model for each design and construction option in Section 5.1;
- Definition of input data to the Construction Model for each design and construction option in Section 5.2; and
- A summary of the principles of the DAT simulation process in Section 4.

However, to make sure that the DAT system ran correctly and yielded meaningful results, we also conducted the following pre-analyses:

1) Used minimum values defined for all geological and construction parameters to make a deterministic estimate of the minimum and total construction cost and duration for each alignment and maximum grade option. The minimum construction cost and time values obtained served as a guide for checking the output of the DAT simulations;
2) Conducted a limited number of DAT simulation runs for each alignment and maximum grade option and compared the output with the deterministic estimates, thus calibrating the DAT process;
3) Tested the sensitivity of the DAT simulation results to the number of simulation runs considering the huge number of geological and construction variables involved. For this purpose, the number of test simulation runs for each option was progressively increased from 100, to 300, to 500, to 750, and finally to 1000. The results obtained from each step were compared with those from the previous one. It was noted that for all the options studied, there was practically no further benefit to increase the number of simulation-runs to more than 1000. Therefore, for the final, production analysis, the number of simulation runs was fixed at 1000.

6.2 Post-Processing of the DAT-Simulation Results

The post processing of the simulation results for each combined alignment maximum grade option mainly involves the application of standard statistical procedures including:

- simple statistical summary of the construction time and cost to yield the minimum, maximum, and the mean at 95% probability, and standard deviation values for the total construction cost and time of each option.
- frequency counting and histogram representation of the variation in the total time and cost.
- fitting of a normal distribution curve to the frequency of total time and cost.
- production of cost versus time scatter plots for comparison.

6.3 The Results of the DAT Analysis

With reference to the procedures given in Section 6.2, the presentation of the post-processed results of the DAT analysis is done using consistently standardized formats.

Step 1 – Separate presentation of the results for each combined alignment maximum grade option (see forward to Sections 6.3.1 to 6.3.4 for the 4 options analyzed, respectively), in the order given below.

1. A scatter plot showing the direct output from DAT in terms of the total construction time and cost of the 1000 simulation-runs for each option;
2. A time-frequency histogram, fitted with a cumulative normal distribution curve;
3. A table presenting the summary statistics of the construction time including its minimum, maximum, mean, at-95%-probability, and standard deviation values for the total construction cost and time of each option
4. The cost-frequency histogram, fitted with a cumulative normal distribution curve;
5. A table presenting the summary statistics of the construction cost including its minimum, maximum, and the mean at 95% probability and standard deviation values for the total construction cost and time of each option.

Specifically,

Section 6.3.1 presents the results of the I-5 Alignment with 3.5% maximum grade option (Figure 6.1, Figure 6.2, Table 6.1, Figure 6.3, and Table 6.2).

Section 6.3.2 presents the results of the I-5 Alignment with 2.5% maximum grade option (Figure 6.4, Figure 6.5, Table 6.3, Figure 6.6, and Table 6.4).

Section 6.3.3 presents the results of the AV Alignment with 3.5% maximum grade option (Figure 6.7, Figure 6.8, Table 6.5, Figure 6.9, and Table 6.6).

Section 6.3.2 presents the results of the AV Alignment with 2.5% maximum grade option (Figure 6.10, Figure 6.11, Table 6.7, Figure 6.12, and Table 6.8).

Step 2 – Comparative presentation of all the results for the four combined alignment maximum grade options (see forward to **Sections 6.3.5**), in the order given below.

1. A superimposed, scatter plot (Figure 6.13) showing the direct output from DAT in terms of the total construction time and cost of the 1000 simulation-runs;
2. A summary table presenting the global statistics of the construction time and cost including the minimum, the maximum, and the mean, at 95% probability and standard deviation values for the total construction cost and time of all options (Table 6.9).

6.3.1 The results of the I-5 Alignment with 3.5% maximum grade option

Figure 6.1 Total Construction Time vs. Cost scatter plot of the option of I-5 Alignment with 3.5% maximum grade

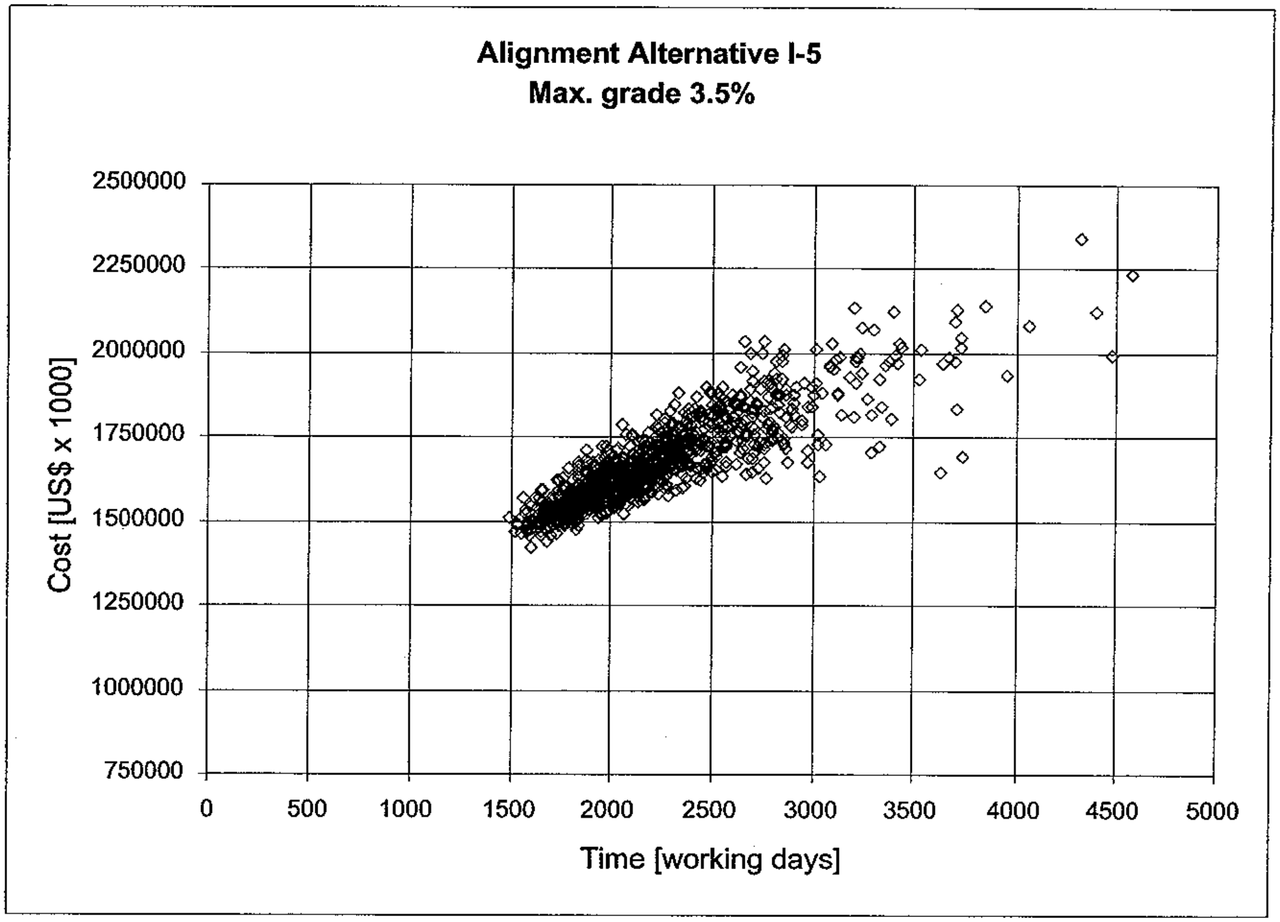


Figure 6.2 Total Construction Time histogram of the option of I-5 Alignment with 3.5% maximum grade

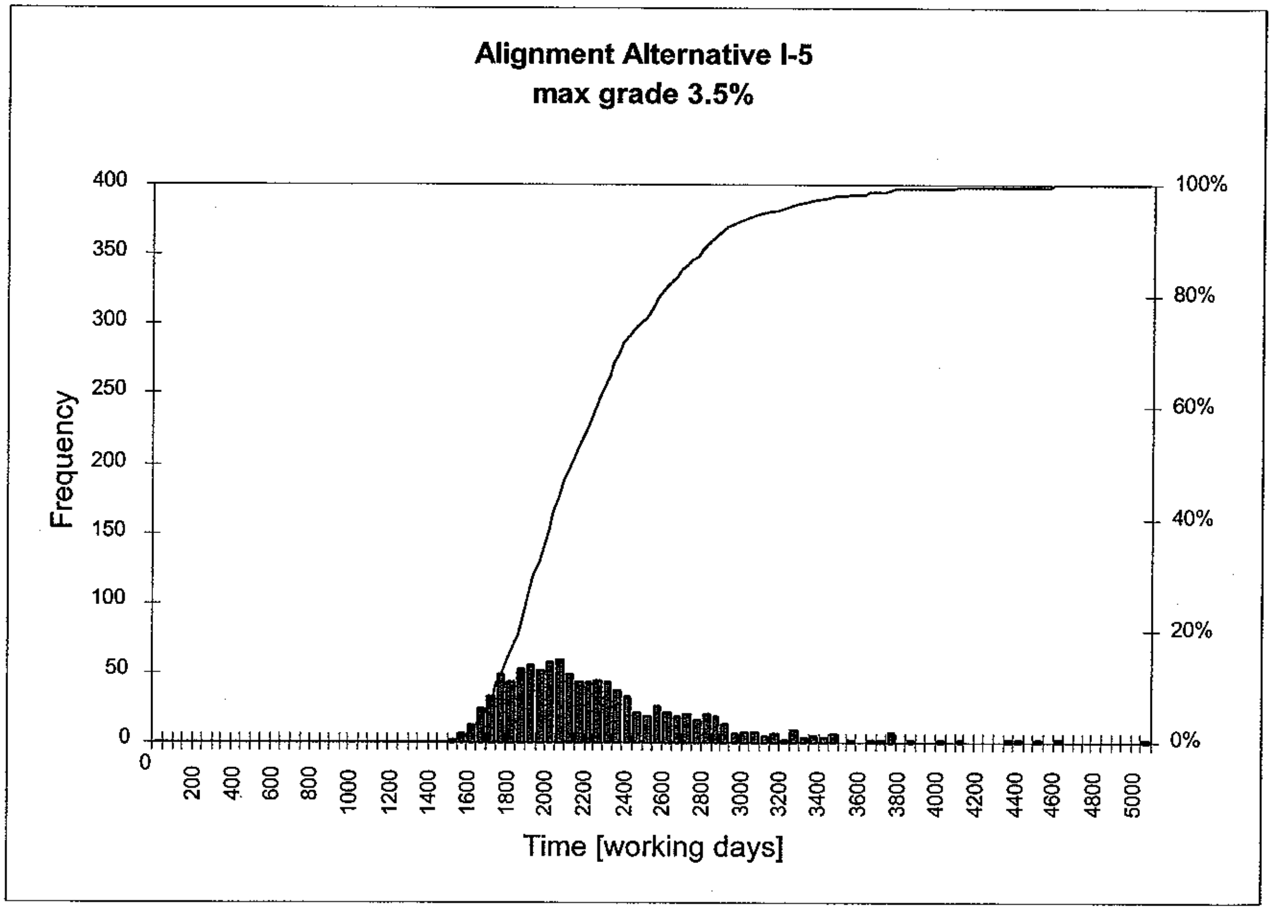


Table 6.1 Statistical data about the Total Construction Time of the option of I-5 Alignment with 3.5% maximum grade

Alignment Alternative I-5 Max grade 3.5%	Construction time	
	Unit	Value
Number of simulations	[-]	1000
Mean value	[working days]	2218
Median value	[working days]	2111
St. Deviation	[working days]	471
Minimum value	[working days]	1492
Value at 95%	[working days]	3100
Difference between 95% value and mean value	[working days]	882
Difference between 95% value and min value	[working days]	1608

Figure 6.3 Total Construction Cost histogram of the option of I-5 Alignment with 3.5% maximum grade

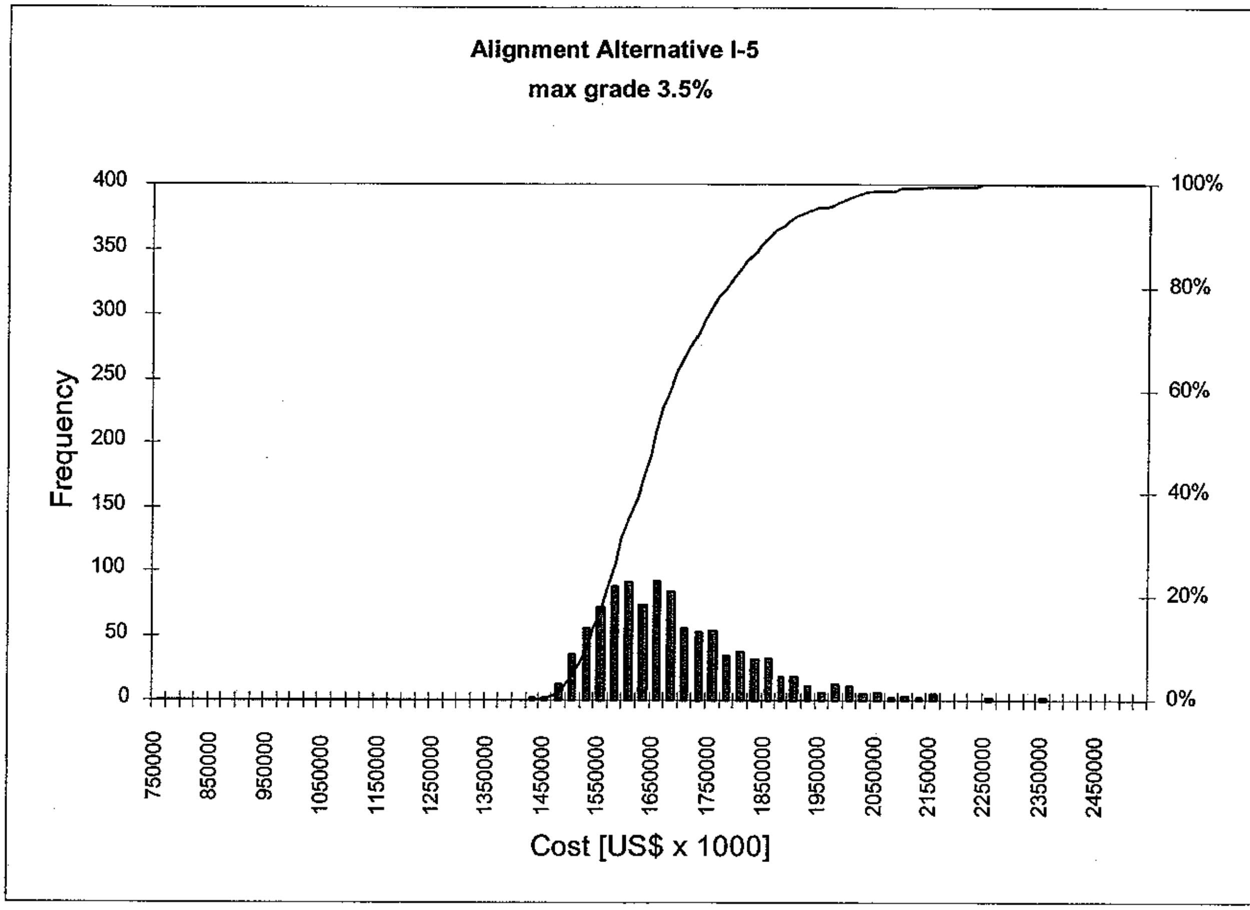


Table 6.2 Statistical data about the Total Construction Cost of the option of I-5 Alignment with 3.5% maximum grade

Alignment Alternative I-5 Max grade 3.5%	Construction cost	
	Unit	Value
Number of simulations	[-]	1000
Mean value	[US$ x 1000]	1670080
Median value	[US$ x 1000]	1643417
St. Deviation	[US$ x 1000]	133507
Minimum value	[US$ x 1000]	1420421
Value at 95%	[US$ x 1000]	1925000
Difference between 95% value and mean value	[US$ x 1000]	254920
Difference between 95% value and min value	[US$ x 1000]	504579

6.3.2 The results of the I-5 Alignment with 2.5% maximum grade option

Figure 6.4 Total Construction Time vs. Cost scatter plot of the option of I-5 Alignment with 2.5% maximum grade

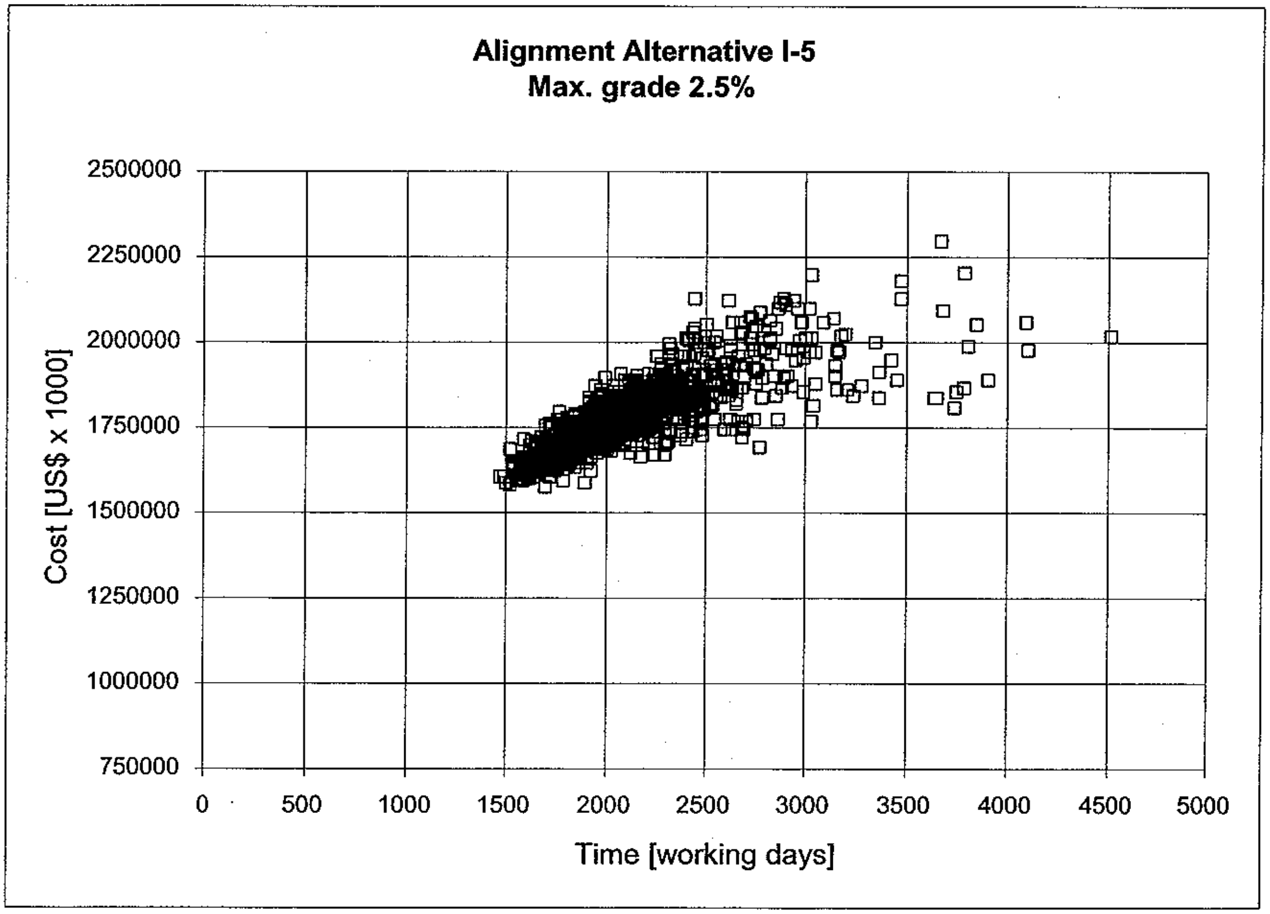


Figure 6.5 Total Construction Time histogram of the option of I-5 Alignment with 2.5% maximum grade

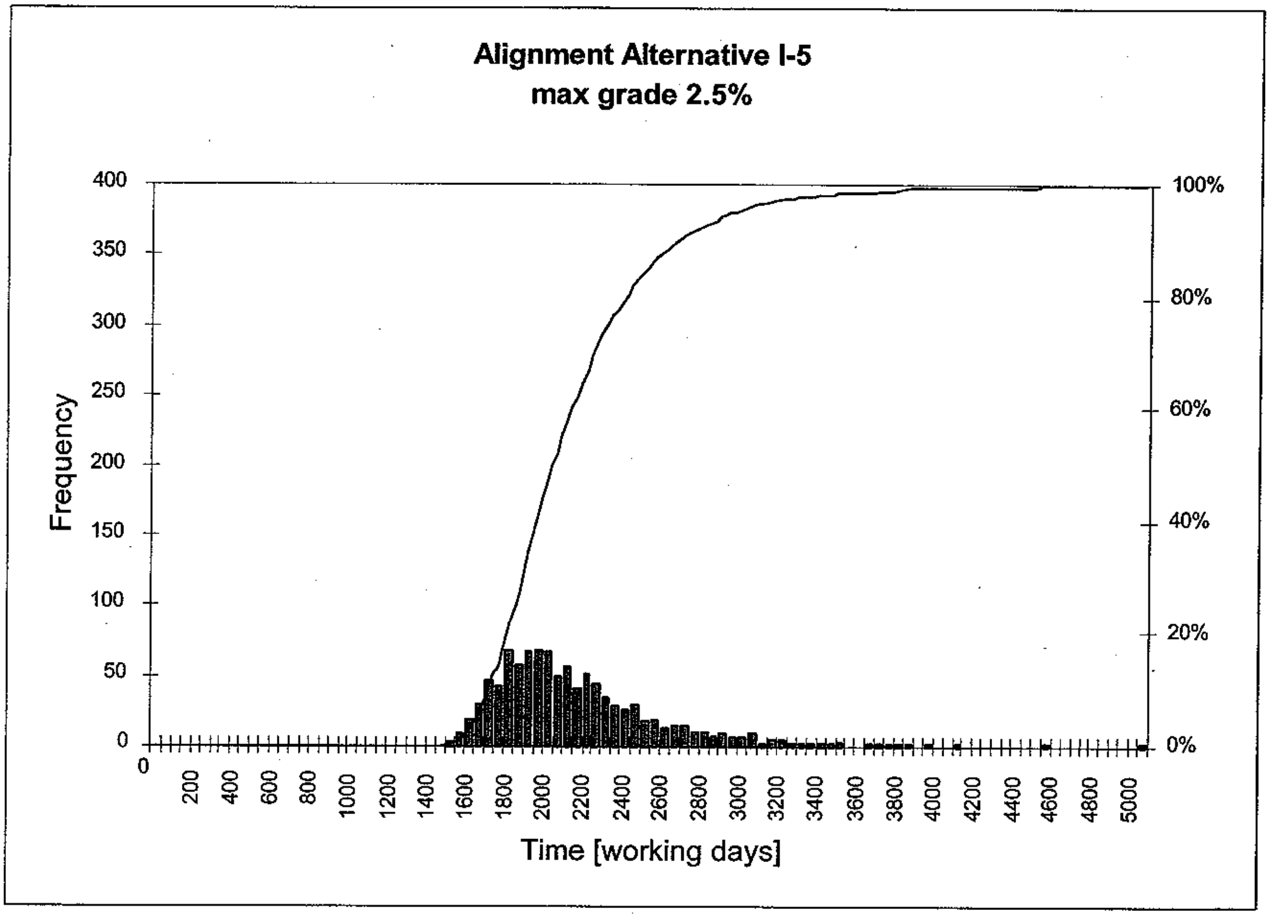


Table 6.3 Statistical data about the Total Construction Time of the option of I-5 Alignment with 2.5% maximum grade

Alignment Alternative I-5 Max grade 2.5%	Construction time	
	Unit	Value
Number of simulations	[-]	1000
Mean value	[working days]	2124
Median value	[working days]	2027
St. Deviation	[working days]	431
Minimum value	[working days]	1470
Value at 95%	[working days]	2900
Difference between 95% value and mean value	[working days]	776
Difference between 95% value and min value	[working days]	1430

Figure 6.6 Total Construction Cost histogram of the option of I-5 Alignment with 2.5% maximum grade

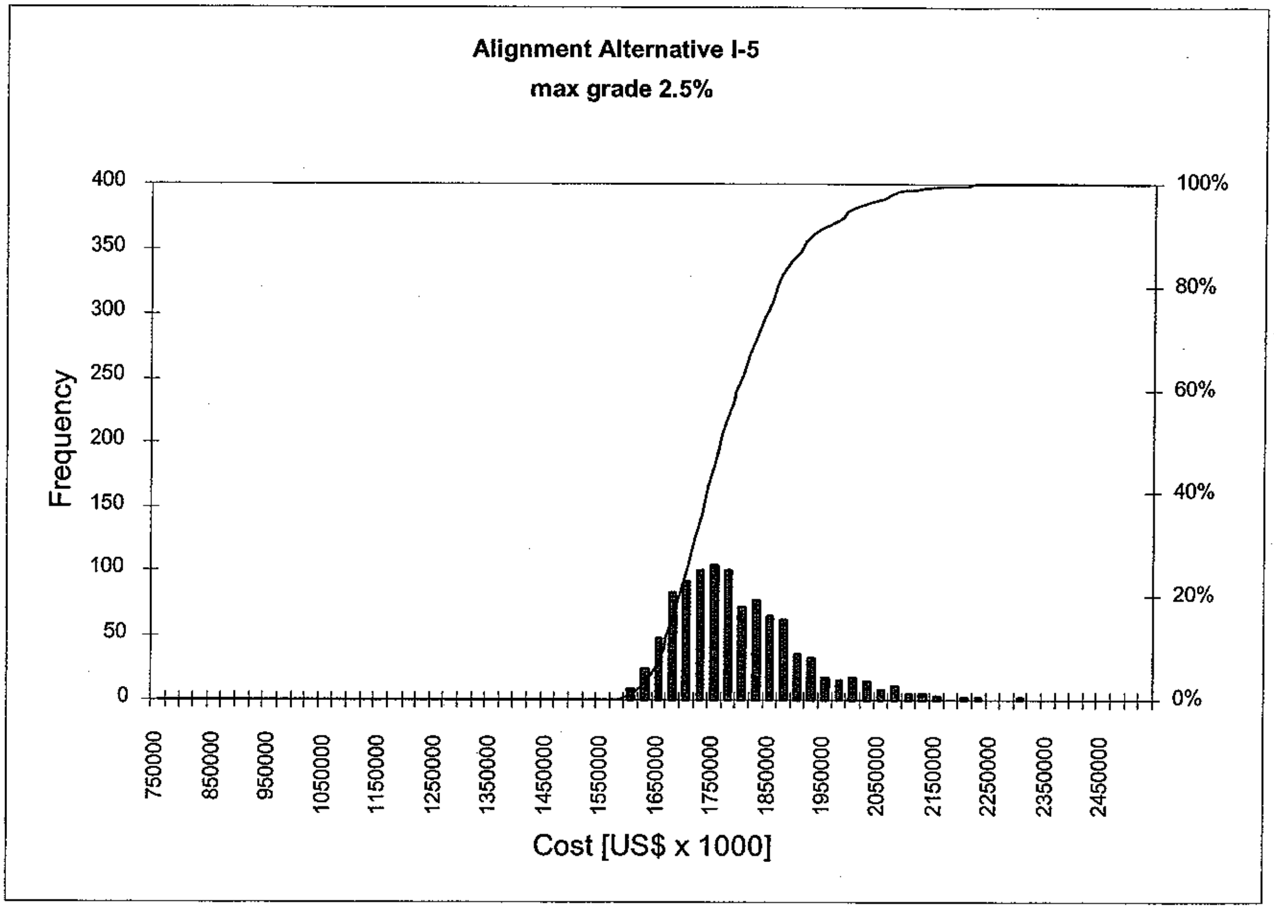


Table 6.4 Statistical data about the Total Construction Cost of the option of I-5 Alignment with 2.5% maximum grade

Alignment Alternative I-5 Max grade 2.5%	Construction cost	
	Unit	Value
Number of simulations	[-]	1000
Mean value	[US$ x 1000]	1779101
Median value	[US$ x 1000]	1758361
St. Deviation	[US$ x 1000]	110232
Minimum value	[US$ x 1000]	1576264
Value at 95%	[US$ x 1000]	1975000
Difference between 95% value and mean value	[US$ x 1000]	195899
Difference between 95% value and min value	[US$ x 1000]	398736

6.3.3 The results of the AV Alignment with 3.5% maximum grade option

Figure 6.7 Total Construction Time vs. Cost scatter plot of the option of AV Alignment with 3.5% maximum grade

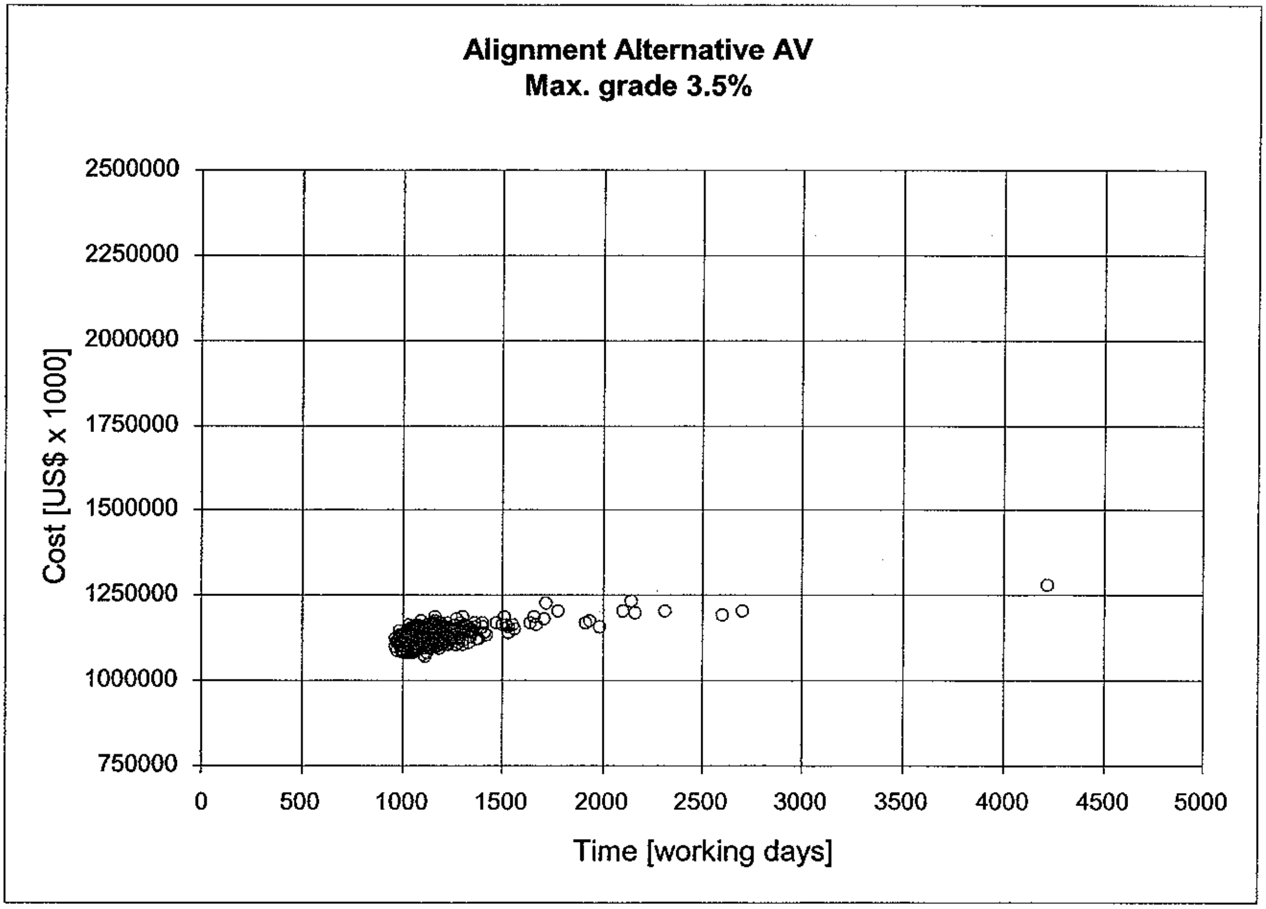


Figure 6.8 Total Construction Time histogram of the option of AV Alignment with 3.5% maximum grade

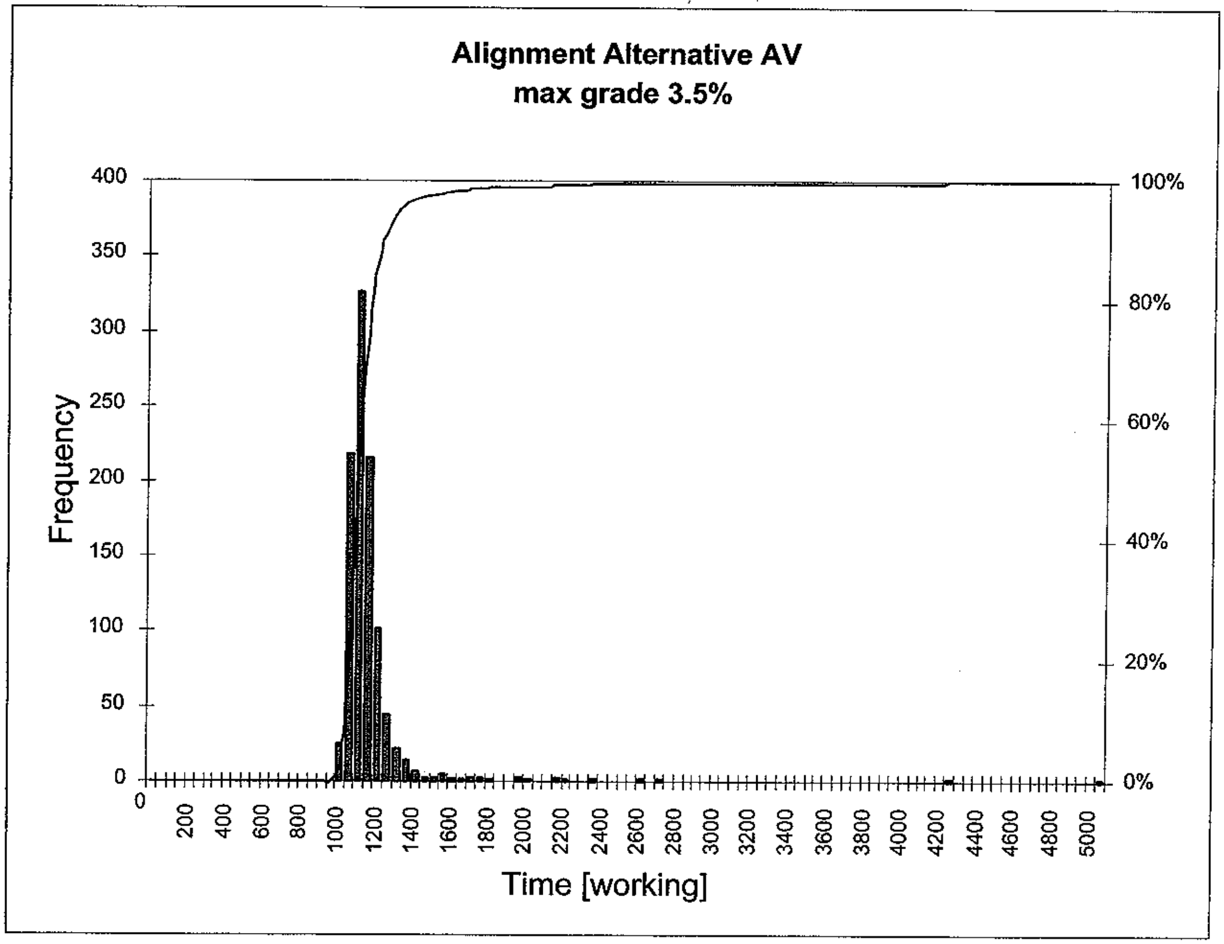


Table 6.5 Statistical data about the Total Construction Time of the option of AV Alignment with 3.5% maximum grade

Alignment Alternative AV Max grade 3.5%	Construction time	
	Unit	Value
Number of simulations	[-]	1000
Mean value	[working days]	1125
Median value	[working days]	1089
St. Deviation	[working days]	217
Minimum value	[working days]	962
Value at 95%	[working days]	1250
Difference between 95% value and mean value	[working days]	125
Difference between 95% value and min value	[working days]	288

Figure 6.9 Total Construction Cost histogram of the option of AV Alignment with 3.5% maximum grade

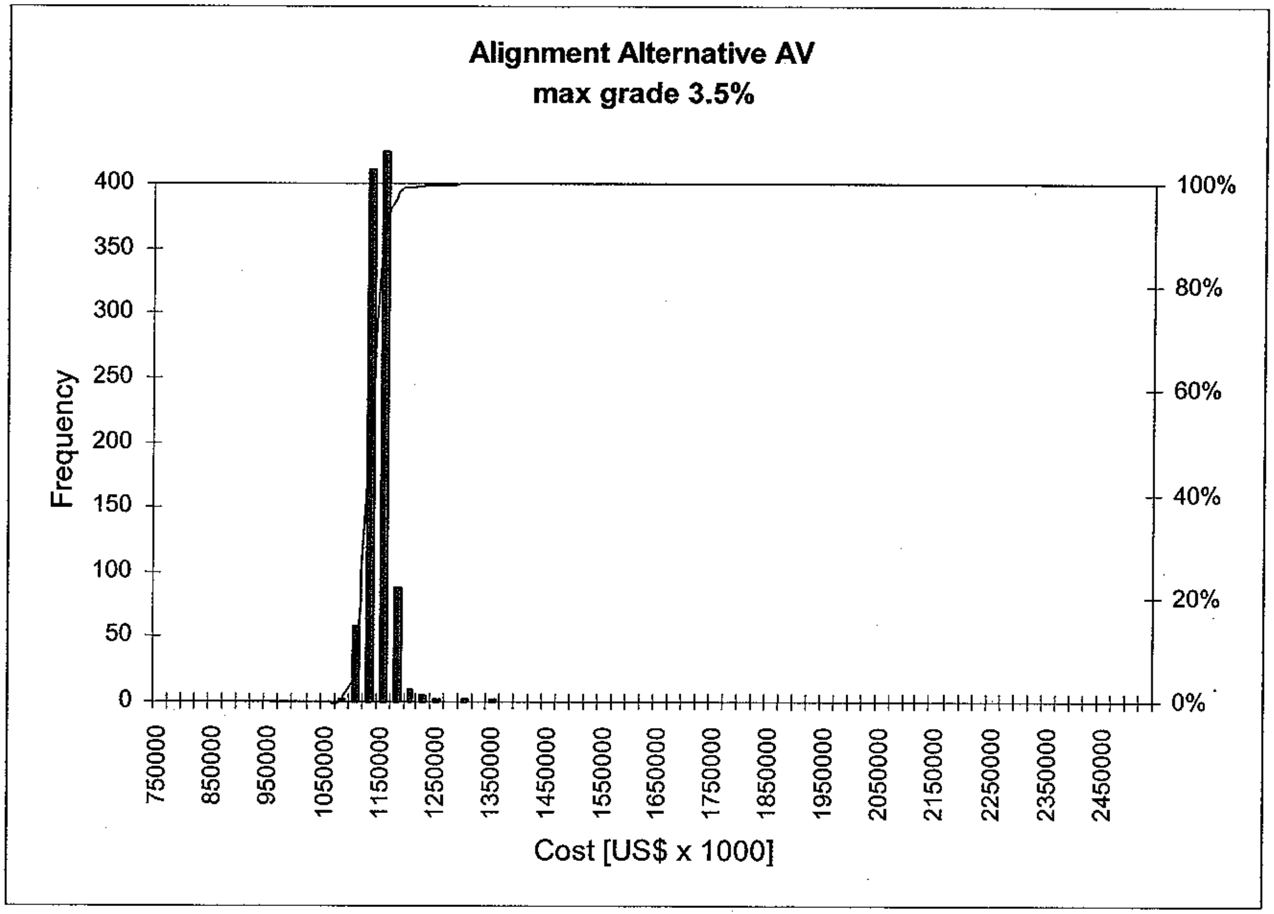


Table 6.6 Statistical data about the Total Construction Cost of the option of AV Alignment with 3.5% maximum grade

Alignment Alternative AV Max grade 3.5%	Construction cost	
	Unit	Value
Number of simulations	[-]	1000
Mean value	[US$ x 1000]	1127511
Median value	[US$ x 1000]	1125936
St. Deviation	[US$ x 1000]	21023
Minimum value	[US$ x 1000]	1073210
Value at 95%	[US$ x 1000]	1150000
Difference between 95% value and mean value	[US$ x 1000]	22489
Difference between 95% value and min value	[US$ x 1000]	76790

6.3.4 The results of the AV Alignment with 2.5% maximum grade option

Figure 6.10 Total Construction Time vs. Cost scatter plot of the option of AV Alignment with 2.5% maximum grade

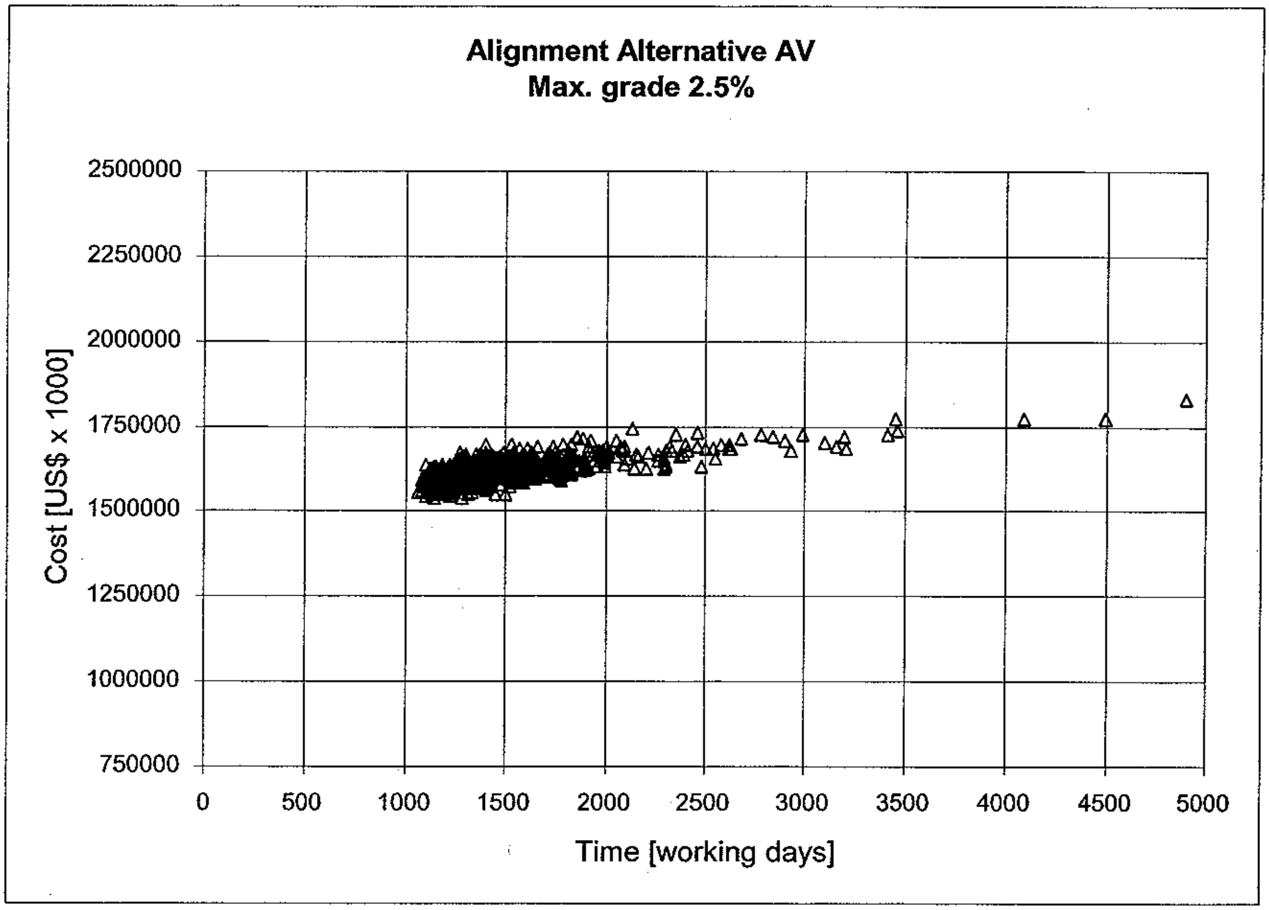


Figure 6.11 Total Construction Time histogram of the option of AV Alignment with 2.5% maximum grade

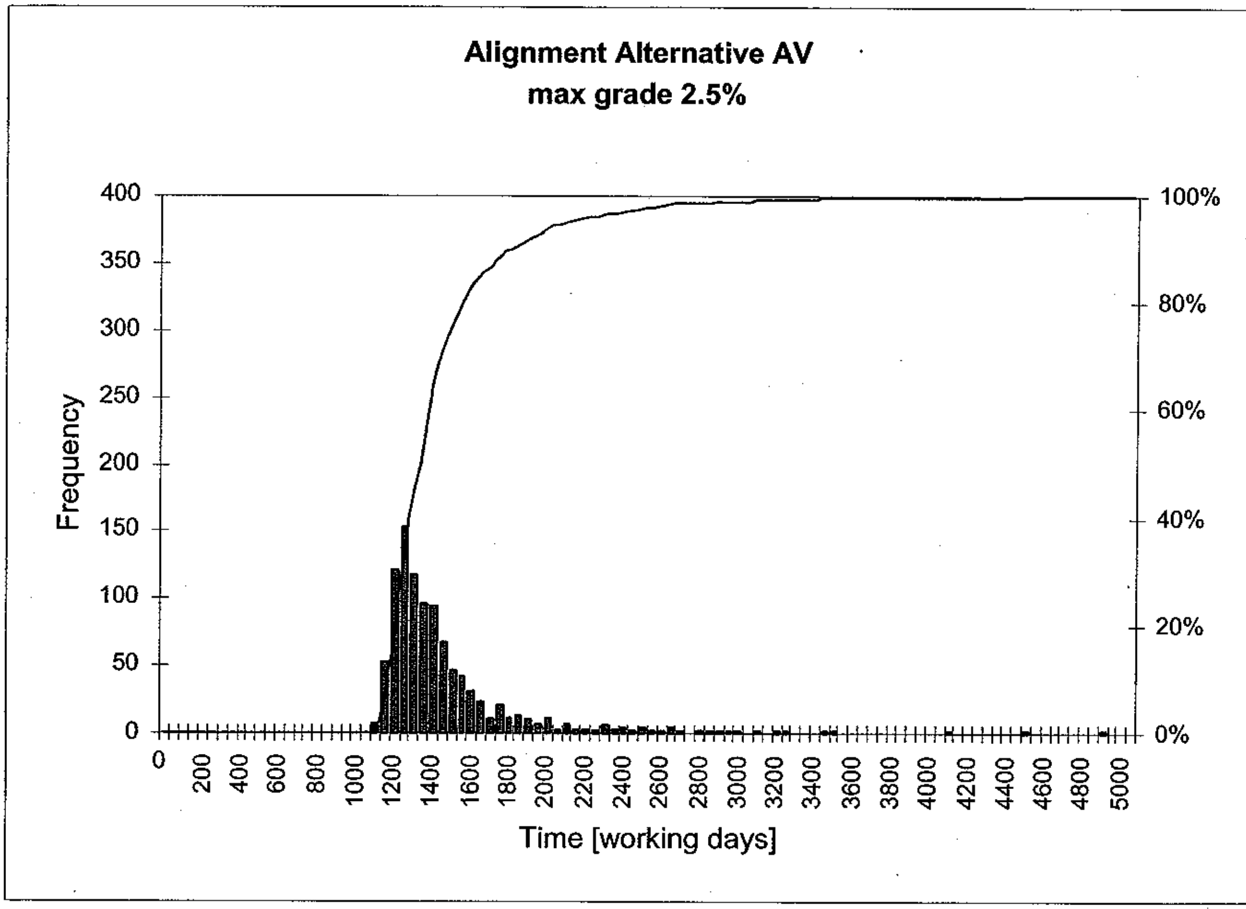


Table 6.7 Statistical data about the Total Construction Time of the option of AV Alignment with 2.5% maximum grade

Alignment Alternative I-5AV Max grade 2.5%	Construction time	
	Unit	Value
Number of simulations	[-]	1000
Mean value	[working days]	1430
Median value	[working days]	1321
St. Deviation	[working days]	370
Minimum value	[working days]	1060
Value at 95%	[working days]	2050
Difference between 95% value and mean value	[working days]	620
Difference between 95% value and min value	[working days]	990

Figure 6.12 Total Construction Cost histogram of the option of AV Alignment with 2.5% maximum grade

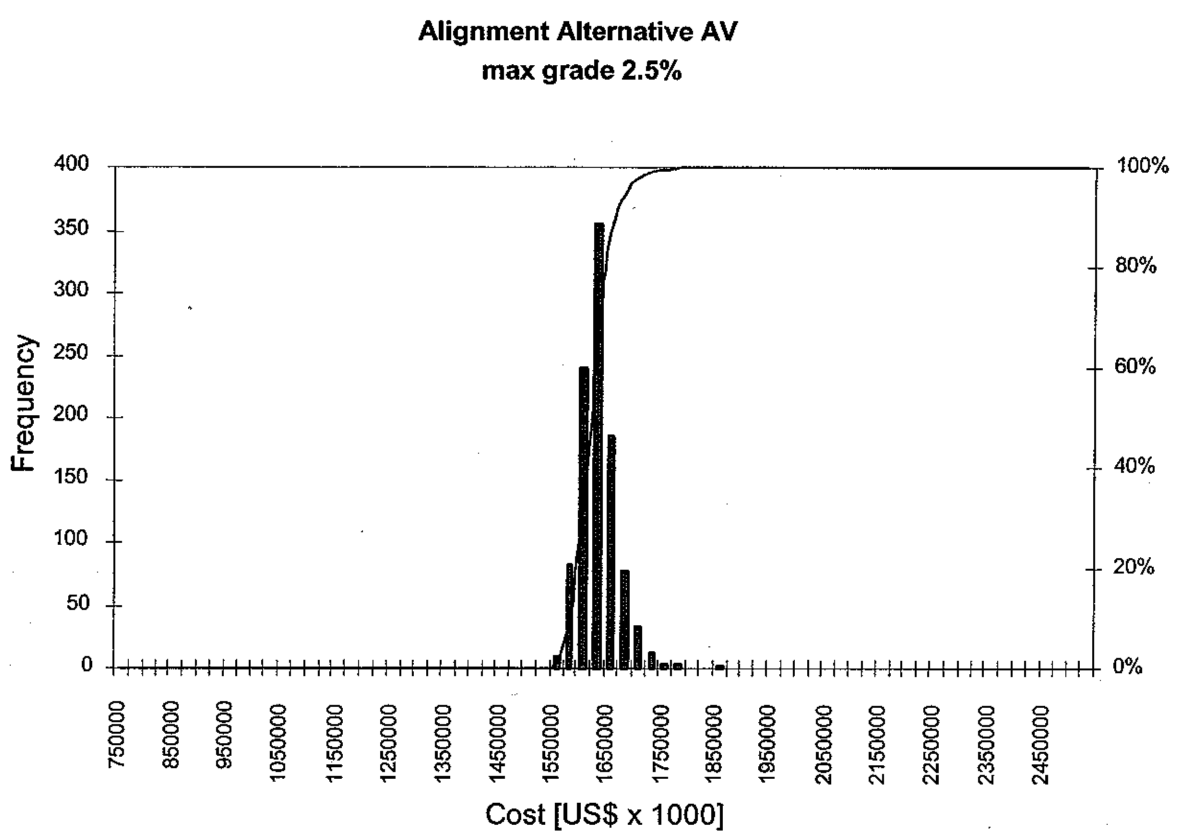


Table 6.8 Statistical data about the Total Construction Cost of the option of AV Alignment with 2.5% maximum grade

Alignment Alternative AV Max grade 2.5%	Construction cost	
	Unit	Value
Number of simulations	[-]	1000
Mean value	[US$ x 1000]	1614790
Median value	[US$ x 1000]	1610143
St. Deviation	[US$ x 1000]	34021
Minimum value	[US$ x 1000]	1537212
Value at 95%	[US$ x 1000]	1675000
Difference between 95% value and mean value	[US$ x 1000]	60210
Difference between 95% value and min value	[US$ x 1000]	137788

6.3.5 Comparative presentation of all the results

Figure 6.13 Scatter plot showing the results of all 4 options for comparison

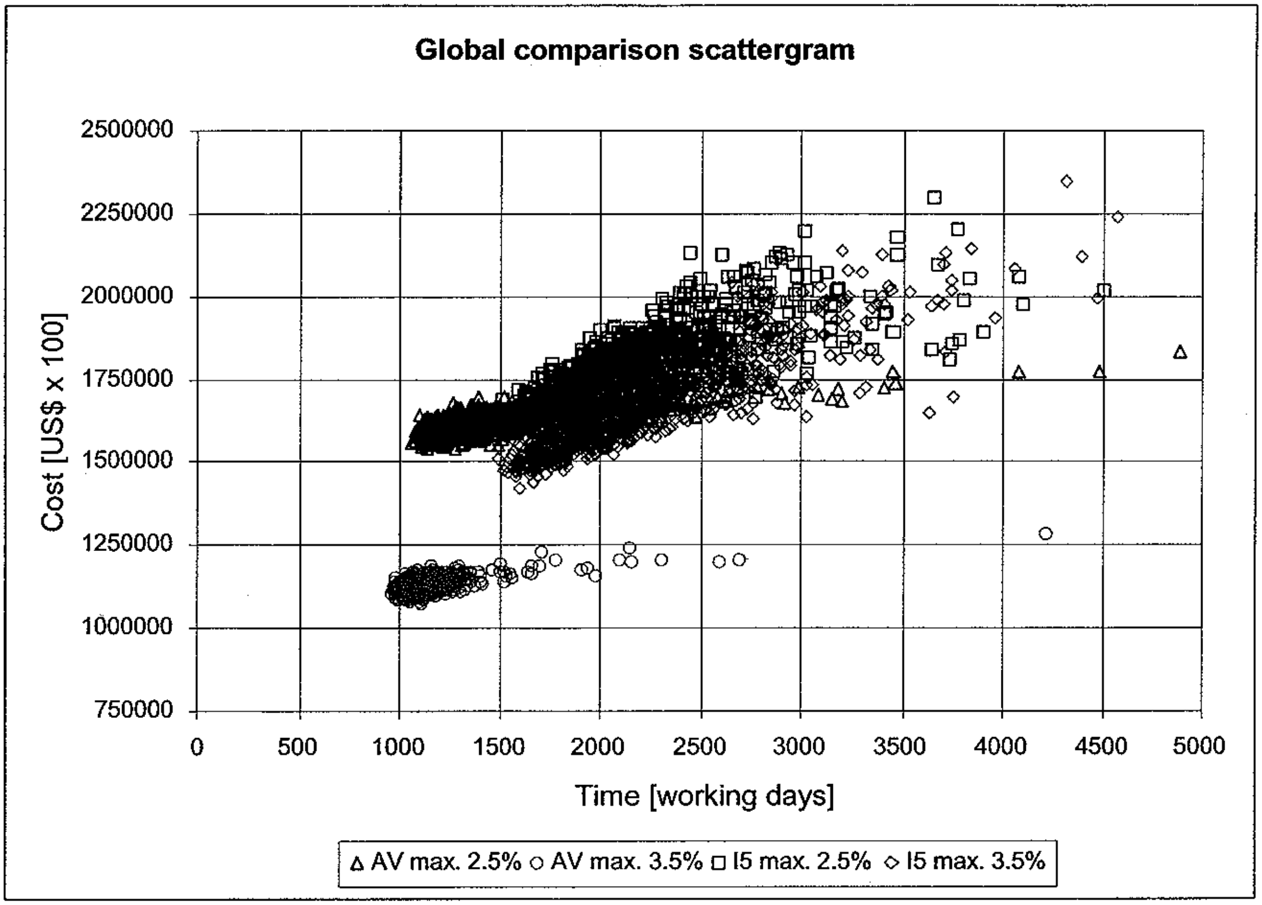


Table 6.9 Global statistics of all 4 options for comparison

		Alignment Alternative I-5		Alignment Alternative AV	
		Max. grade 3.5%	Max. grade 2.5%	Max. grade 3.5%	Max. grade 2.5%
Construction time analysis	**Unit**	**Value**	**Value**	**Value**	**Value**
Number of simulations	[-]	1000	1000	1000	1000
Mean value	[working days]	2218	2124	1125	1430
Median value	[working days]	2111	2027	1089	1321
St. Deviation	[working days]	471	431	217	370
Minimum value	[working days]	1492	1470	962	1060
Value at 95%	[working days]	3100	2900	1250	2050
Difference between 95% value and mean value	[working days]	882	776	125	620
Difference between 95% value and min value	[working days]	1608	1430	288	990
Coefficient of Variation	[%]	21.2	20.3	19.3	25.9
Construction cost analysis	**Unit**	**Value**	**Value**	**Value**	**Value**
Number of simulations	[-]	1000	1000	1000	1000
Mean value	[US$ x 1000]	1670080	1779101	1127511	1614790
Median value	[US$ x 1000]	1643417	1758361	1125936	1610143
St. Deviation	[US$ x 1000]	133507	110232	21023	34021
Minimum value	[US$ x 1000]	1420421	1576264	1073210	1537212
Value at 95%	[US$ x 1000]	1925000	1975000	1150000	1675000
Difference between 95% value and mean value	[US$ x 1000]	254920	195899	22489	60210
Difference between 95% value and min value	[US$ x 1000]	504579	398736	76790	137788
Coefficient of Variation	[%]	8.0	6.2	1.9	2.1

6.4 Discussion of the Results

The results obtained from the DAT simulations must be correctly interpreted in the light of the underlining assumptions.

Considering the variation in the total construction costs (see Figure 6.13 and Table 6.9), it can be observed that, for both Alignment alternatives there is a clear positive relationship between the increase in the average cost and the total length of tunneling (when changing from the 3.5%-max-grade to the 2.5%-maximum grade), as one would normally expect.

Considering the uncertainty about costs which can be measured by the Coefficients of Variation, see Table 6.9), both maximum grade options of the I-5 alignment show higher dispersion than those of the corresponding AV alignment which can be attributed to the more adverse, geologic conditions found along the I-5 alignment.

Additionally, the augmented tunneling length for the AV alignment implies an increase in the spread of results (COV from 1.9% to 2.1%), which is consistent with the increased uncertainties associated with more tunnel stretches running through geologically difficult zones. [Considering the actual tunnel configurations which do not differ from the 2.5% to the 3.5% maximum grade option, the opposite trend of COV, from 8.0% to 6.2%, is evident for the I-5 alignment.]

Similar considerations can be made about the total construction times, especially for the I-5 alignment. The reduced average total construction time for the 2.5% maximum grade configuration, which has approximately 1.5 miles of more tunneling than the 3.5% configuration, derives from the different construction schemes adopted, where one more TBM had to be introduced to optimize the whole construction scheme.

In addition to the above general comments, the following specific observations can be made:

1) The shape of the clouds for the AV alignment (both 3.5% and 2.5% grade options), as shown in the comparative scatter plot of Figure 6.13, is quite different from those of the I-5 alignment (both grade options).

   In the case of the AV Alignment, the cloud tends to close down towards the high ends (of time and cost) with increasingly fewer number of points, while that of the I-5 Alignment is not only wider but also open, with a lower concentration of results in the desired lower range of total construction cost and duration.

   Without entering into the statistical data and the absolute values, the discrepancy above means that the uncertainty of the result in the I-5 alignment is much higher than in the AV alignment.

2) For all four options studied, the dispersion of results is always wider in the time direction than in the cost direction. This is because a linear correspondence between an increase of time and an increase of costs is not foreseen. For tunnel excavation by TBM, supported by pre-cast concrete lining, there is a wide variation in the advance rate due to variations in ground conditions. However, there is no significant variation in the construction cost per linear meter of tunnel. For the HSR Project, the combination of TBM excavation with pre-cast concrete lining is the construction method adopted for almost all tunnels involved in each option.

3) The scattering aspect revealed in Item 1) above is shown clearly by the histograms, especially in the area of costs. Both grade options of the AV Alignment have an extremely "slim" distribution (see Figures 6.9 and 6.12) of cost, with quite small differences between the 95% value and the minimum value (being 76 millions of USD for the 3.5% maximum grade option and 137 millions of USD for the 2.5% maximum grade option, respectively, see Table 6.6 and Table 6.8). The same results are much more uncertain for the I-5 Alignment, with very large differences between the 95% value and the minimum value (being 500 millions of USD and 400 millions of USD for the 3.5%, see Table 6.2, and the 2.5% maximum grade option, see Table 6.4, respectively.)

4) In terms of the mean construction cost, the 3.5% maximum grade option of the AV alignment is about 40% cheaper than that of the corresponding I-5 alignment, while this advantage is reduced for the 2.5% maximum grade option, being about 15% cheaper, due to the increased total length of tunnelling works involved. Furthermore, it should be noted that the increased tunnel length for the AV alignment at the 2.5% maximum grade means savings in costs for construction of the external works and for the mitigation of the environmental impact in the stretches replaced by tunnels.

5) The time histograms of both maximum grade options of the I-5 alignment have similar distributions (see Figure 6.2 and Figure 6.5), due to the fact that the differences in the construction schemes do not affect the final construction time. The main difference consists in the existence of a second set of seismic chambers to cross the San Andrea Fault Zone. This feature introduces additional, costs, but not time because the construction of the second couple of seismic chambers was foreseen to be done mainly during the long period of procurement and assembly of the TBMs. The TBMS will start their tunnel excavation from the chambers and, thus will not affect the final construction time.

6) The 2.5% maximum grade option of the AV alignment has a consistently lower range of variation in the total construction time (with a difference of 990 working days between the 95% value and the minimum value, see Table 6.7), and the 3.5% maximum grade option has an even lower range (being only 288 working days, see Table 6.5). However, the corresponding differences for the I-5 alignment are 1608 and 1430 working days respectively for the 3.5% (see Table 6.1) and the 2.5% maximum grade option (see Table 6.3). These differences between the AV and the I-5 alignment derive mainly from the differences in the geological conditions involved: the relatively shorter and shallower tunnels on the AV alignment are associated with less geological difficulties and thus a lower degree of uncertainty, compared with the long and deep tunnels on the I-5 Alignment.

7) For the 3.5% maximum grade option, the mean construction time required for the I-5 alignment is almost twice as much as that required for the AV alignment (2218 working days against 1125 working days, see Table 6.9). The same trend is basically true also for the 2.5% maximum grade option, with a slight increase in the mean construction time for the AV alignment, due to increased total length of tunneling (see also Table 3.1).

8) It should be pointed out that our DAT analysis does not simulate the financial consequences associated with increased construction duration which could change significantly the forecast of the total investment cost. This financial impact of

construction duration will definitely further magnify the current differences in the construction costs between the I-5 options and the AV options.

Finally, with reference to all the histograms fitted with a cumulative normal distribution curve, the risk of exceeding certain cost or time limits can be easily evaluated if such limits or targets are known.

The conclusions derived from the DAT-simulation results are presented in Section 7.

7. CONCLUSIONS AND RECOMMENDATIONS

Given the large amount of tunneling works involved (see Table 3.1), the Bakersfield to Los Angeles Corridor itself, be it the I-5 alignment or the Antelope Valley alignment, is a mega project.

The potential, typical risks that may be encountered in a mega tunneling project are:

1) Risk of encountering adverse conditions due to the inherent uncertainties of ground and groundwater conditions – leading to significant cost overruns and project delay;

2) The potential for accidents during tunneling work and, later on, during operation;

3) Risk to the health and safety of workers and third party individuals, including personal injury and, in extreme cases, loss of life;

4) Construction risks, such as choice of a wrong type of TBM, ground-squeezing behavior, face collapses; and production of materials causing hazardous environmental conditions;

5) Financial risks to the owner, such as delay in completion of the contract or cost overruns;

6) Contractual risks, such as additional work not covered, time delays, disputes, claims and litigation.

The underground construction industry seems particularly prone to disputes. This is most likely because of the risks and uncertainties associated with subsurface conditions and the costly plant and equipment required (for example, the TBM and its associated back up gear).

Traditionally, the potential risks listed above have been managed indirectly through the engineering decisions taken during project development. This approach is often found to be inadequate during construction. Many recent case histories have demonstrated that risk management can be significantly improved by using systematic risk management techniques throughout the tunneling project development. The use of these techniques can ensure that most potential problems are identified and addressed in a timely fashion so that appropriate and cost effective risk reducing measures can be implemented. The use of risk management in the early stages of a tunnel project is essential, particularly at the beginning of the planning process where major decisions, such as choice of alignment and selection of construction methods, can be influenced.

The study presented in this report was commissioned for two main reasons, (1.) Specific uncertainties in the tunneling process were not adequately integrated in earlier studies commissioned by the Authority, and (2.) to identify the optimum alignment with respect to minimizing capitol investment and risk of construction cost overruns and costly delays.

As pointed out in Section 1.2.2, the earlier studies of the Authority have focused on minimizing tunnel requirements and cost (Corridor Evaluation study and QUANTM study) and minimizing potential environmental impacts (the Screening Evaluation) by avoiding sensitive zones in identifying the potentially suitable routes. However, there is a limit to these reductions due to the constraints imposed by the specific topography and tectonic setting of the region as well as the high speed train technology. Furthermore, for the limited number of potentially suitable routes identified by the previous screening studies, and subsequently confirmed by the QUANTM analysis, the various categories of risks, especially the geological and construction risks, were not considered. In the opinion of Transmetrics/Geodata, these other risks are as important as those already considered by the Authority. They are also critical in the final choice of the optimum alignment/route for the mega tunneling project.

Consequently, the study commissioned by the City of Palmdale and undertaken by Transmetrics/Geodata represents a complementary, step forward in the development process of the Project.

It is understood from the beginning of this report that, to perform an alignment specific risk analysis, focusing on the geological and constructional aspects, requires specific information about the ground conditions of each potentially suitable alignment. However, most of the required information is not directly available because no preliminary site-specific investigations have been made.

To overcome this problem, we adopted the common practice of utilizing our tunneling experience and judgment as well as USGS data and reports in lieu of precise, in situ explorations and measurements. In addition, full use was made of the information contained in the Preliminary Engineering Feasibility Study of PBQD. We acquired relevant reports and maps from the USGS to study the geomorphological, geological, hydrogeological, and geotechnical conditions of the two alternative alignment corridors, establishing foreseeable ground models. We also made a preliminary design of both alignments, defining the corresponding construction schemes based on our European experience for similar projects.

To facilitate the comparison of the geological and construction risks involved in the two alternative alignments and also to further overcome the problem of limited data, we adopted a probabilistic model that incorporates the impact of different geological factors on the risks and productivity. The specific model adopted was developed at the Massachusetts Institute of Technology and is called Decision Aids in Tunneling (DAT). The model allows for the comparison, in terms of construction time and cost, of various, feasible, design and construction solutions for a tunneling project, and for quantification of risks related to each solution.

<u>The various analyses presented in this report have demonstrated the following:</u>

- Although the amount of tunneling work involved in the I-5 and the AV alignment are almost the same, be it the 2.5% grade or the 3.5% grade option, the ground conditions along the AV are relatively more favorable and hence involve less construction risks, financial risks, and contractual risks.
- For the 3.5% max grade option, the mean construction time required for the I-5 alignment is almost twice as much as that required for the AV alignment (2218 working days against 1125 working days, see Table 6.9). The same trend is basically true for the 2.5% max grade option, with a slight increase in the mean construction time for the AV alignment due to increased total length of tunneling (see also Table 3.1).

- In terms of the mean construction cost, for the 3.5% max grade option, the Antelope Valley alignment is about 40% cheaper than the I-5 alignment, while this advantage is reduced for the 2.5% max grade option. The 2.5% grade option is 15% cheaper, again due to increased total length of the tunnel. Furthermore, the increased tunnel length for the AV alignment at 2.5% max grade will reduce the costs for the corresponding external works and environmental impact.
- It should be pointed out that the DAT analyses presented in this report do not simulate the financial consequences associated with increased construction duration. If the financial impact due to longer construction duration is taken into consideration, the final results will not only change significantly the forecast of the total investment required for each alignment option, but will also magnify the construction cost differences between the I-5 and the Antelope Valley alignment.

Generally speaking, the findings of this study have confirmed the concerns of the City of Palmdale over the relative risks involved in the two alternative alignments. These findings should also permit the Authority to make more informed decisions regarding the final choice of the best alignment, including the process to be followed before making the final choice.

On the basis of the analysis conducted, we offer the following three specific recommendations:

In general, the construction experience gained by Geodata from similar, International, mega projects is directly useful as information to assist consideration of new alternatives – management, contracting and new technologies – for the current mega project.

1) Reducing uncertainties

Reducing uncertainties through site investigations, especially the preliminary investigation, for mechanized tunneling, is a key investment strategy for project owners because it will directly reduce risks with short, medium and long term benefits.

To facilitate the final choice of the optimum alignment, site investigations should be designed to reduce the geological uncertainties, thus either confirming or negating the geological and construction risks identified in the analyses presented in this report. For this purpose, a proper balance of effort should be maintained between investigating the I-5 alignment and exploring the Antelope Valley alignment.

Once the optimum alignment is selected, it is strongly recommended that critical sections (if not all sections) of the service tunnels should be constructed first, since they can be used as pilot tunnels to investigate the ground conditions and to experiment with the construction techniques to be employed for the construction of the main tunnels later.

2) Development of Innovation – New Technologies

The greatest payoff can be realized by the use of innovation in complex underground projects, especially long and deep tunnels, with difficult or unexplored geology, as in the California High Speed Rail project. In addition to the risks listed previously, there are still potential technological risks. For example, the technical feasibility of realizing the huge, seismic chambers in very wide fault zones, and the technical capacity of the tunneling market to supply the great number of large-diameter TBM's required for realizing this mega tunneling project will be a challenging task.

Innovation means that the new concepts are competently developed, consistent with the limits of current knowledge and experience, and carefully matched to the specific conditions of the project. For this purpose, it is suggested that the Authority work closely with engineers, contractors and manufacturers, as early as possible, to develop innovative solutions to the high risk aspects of the project, bearing in mind that innovation takes time.

3) Contracting Practices

It is now almost universally accepted that "the ground belongs to the Owner" – including the sometimes unknown difficult geologic conditions which will be encountered. Wise Owners recognize this and seek ways to equitably mitigate the risks, sharing and allocating risk to the best entity that can foresee or control that particular risk. Passing risk along without a strategic and equitable approach will often lead to disputes which will eventually have a great impact on the project and the Owner.

It is now accepted by many Owners that the contracting practice of accepting a fixed-cost low bidder from a group of "qualified" contractors, should not be adopted when the jobs are large, the geology uncertain, and potential for extremely high cost overruns escalate. It has been the experience of some Owners that the low-bid contracting system can result in delays, cost overruns, problems with project completion and a long process of claims and litigation. Negotiated contracts with fair allocation of risks among the parties involved could be more cost effective and equitable.

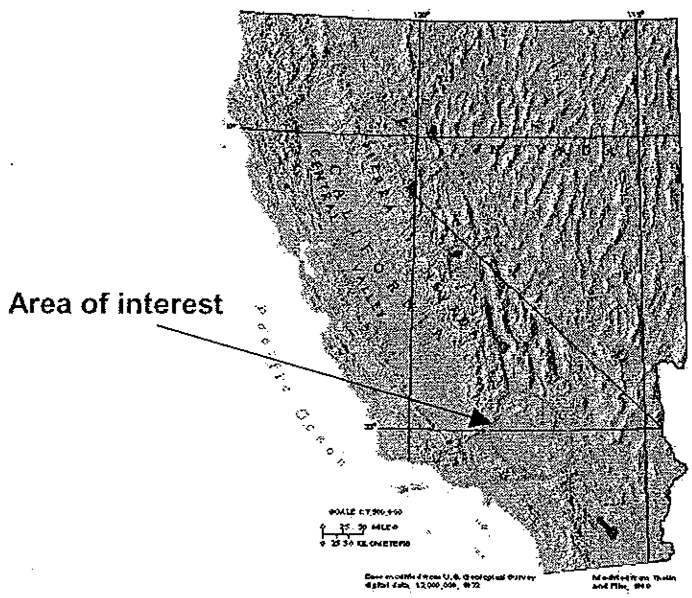
Appendix 1 List of reference geological documents

Type	Title	Year of publ.	Other
Map	Geologic map of the Warm Springs Mountain Quadrangle	1997	scale 1:24,000
Map	Geologic map of the Whitaker Peak Quadrangle	1997	scale 1:24,000
Map	Geologic map of California. Los Angeles sheet	1969	scale 1:250,000
Map	Geologic map of California. Bakersfield sheet	1965	scale 1:250,000
Map	Geologic map of California	1977	scale 1:750,000
Map	Geologic map and cross sections of the southeastern margin of the San Joaquin Valley, California	1984	scale 1:125,000 (contains Bakersfield area)
Map+Paper	Geologic map of the Tehachapi Quadrangle, Kern County, California	1970	scale 1:65,000 (with accompaining explanatory paper)
Map	Geologic map of the San Andreas Fault Zone, Leona Valley, California	1976 (repr. 1984)	scale 1:10,000
Paper+Maps	Geology of the Willow Springs and Rosamond Quadrangles, California	1963	scale 1:62,500
Map+Paper	Geologic map of the Cummings Mountain Quadrangle, Kern County, California	1970	scale 1:65,000 (with accompaining explanatory paper)
Map	Geologic map of the Pearland Quadrangle, California	1953	scale 1:24,000 relevant descriptive notes on the map
Map	Geologic map of the Black Mountain Quadrangle, California	2002	scale 1:24,000
Map	Geologic map of the Liebre Mountain Quadrangle, California	2002	scale 1:24,000
Map	Geologic map of the Pacifico Mountain and Palmdale (south half) Quadrangle, California	2001	scale 1:24,000
Map	Geologic map of the Sleepy Valley and Ritter Ridge Quadrangles, California	1997	scale 1:24,000
Paper+Map	Postcrystalline Deformation of the Pelona Schist Bordering Leona Valley, Southern California	1978	Geological Survey Professional Paper 1039 with annexed geologic map at 1:10,000
Paper+Map	Basement-Rock Correlations Across the White Wolf-Breckenridge-Southern Kern Canyon Falut Zone, Southern Sierra Nevada, California	1986	U.S. Geological Survey Bull. 1651, with annexed geologic map at 1:25,000
Paper+Map	Stratigraphy and Sedimentology of the Eocene Tejon Formation, Western Tehachapi and San Emigdio Mountains, California	1987	U.S. Geological Survey Bull. 1268, with annexed geologic non colour map at 1:62,500
Paper+Map	The Metamorphic and Plutonic Rocks of the Southermost Sierra Nevada, California, and their Tectonic Framework	1989	U.S. Geological Survey Professional Paper 1381, with annexed geologic map at 1:125,000
Map	Geologic map of the Grapevine Quadrangle, California	1973	U.S. Geological Survey open file map, preliminary non colour. Scale 1:24,000
Map	Geologic map of the Pastoria Creek Quadrangle, California	1973	U.S. Geological Survey open file map, preliminary non colour. Scale 1:24,000
Map	Geologic map of the Eagle Rest Peak Quadrangle, California	1973	U.S. Geological Survey open file map, preliminary non colour. Scale 1:24,000
Map	Geologic map of the Santiago Creek Quadrangle, California	1973	U.S. Geological Survey open file map, preliminary non colour. Scale 1:24,000
Map	Geologic map of the Pleito Hills Quadrangle, California	1973	U.S. Geological Survey open file map, preliminary non colour. Scale 1:24,000
Maps (4)+Table	Geologic maps of the Knob Hill, Pine Mountain, Oil Center and Bena Quadrangles, California	1986	U.S. Geological Survey open-file report 86-188, preliminary non colour. Scale 1:24,000
Map+Notes	Preliminary Geologic map of the Val Verde 7.5' Quadrangle, Southern California	1995	U.S. Geological Survey open-file report 95-504, preliminary non colour. Scale 1:24,000
Map+Notes	Preliminary Geologic map of the Oat Mountain 7.5' Quadrangle, Southern California	1995	U.S. Geological Survey open-file report 95-89, preliminary colour. Scale 1:24,000
Map+Notes	Preliminary Geologic map of the Mint Canyon 7.5' Quadrangle, Southern California	1996	U.S. Geological Survey open-file report 96-89, preliminary colour. Scale 1:24,000
Map+Notes	Preliminary Geologic map of the Newhall 7.5' Quadrangle, Southern California	1995	U.S. Geological Survey open-file report 95-503, preliminary non colour. Scale 1:24,000
Notes	Geologic map and Digital Database of the Apache Canyon 7.5' Quadrangle, Ventura and Kern Counties, California	2000	U.S. Geological Survey open-file report 00-359. Stratigraphy, structure and units description. NO MAP
Notes	Preliminary Geologic map of the San Fernando 7.5' Quadrangle, Southern California: a Digital Database	1997	U.S. Geological Survey open-file report 97-163. Just a description of the adopted GIS system
Map	Preliminary Geologic map of the Mojave Quadrangle, California	1959	scale 1:62,500
Map	Geologic map of the Lancaster Quadrangle, Los Angeles County, California	1960	scale 1:62,500
Map	State of California - Special Studies Zones. Palmdale Quadrangle	1979	scale 1:24,000 topographic map with tectonic lineaments (potentially active faults)
Map	State of California - Special Studies Zones. Ritter Ridge Quadrangle	1979	scale 1:24,000 topographic map with tectonic lineaments (potentially active faults)
Maps (13)	Topographic maps along I-5 route	-	scale 1:24,000
Maps (24)	Topographic maps along SR-14 (via Palmdale) route	-	scale 1:24,000

APPENDIX 2 GEOLOGIC SETTING

2.1 Physiography of the region

The physiography of the region is a product of the geologic history of the area. Several coastal mountain ranges underlain by severely folded, faulted, mostly metamorphosed marine and continental sediments, forming the Pacific Border and the Lower Californian Physiographic Provinces.



Thelin, G.P., and Pike, R.J., 1990, Digital shaded relief map of the conterminous United States: Menlo Park, California, U.S. Geological Survey digital image processing, scale 1:3,500,000

Figure A2.1 Digital, shaded relief map showing the high rugged California mountain ranges surrounding the low lying Central Valley (modified after USGS Groundwater Atlas of United States; California, Nevada)

In the interior, the granitic rocks that underlie the fault blocks of the Sierra Nevada and the volcanic rocks of the southern Cascade Mountains join to form the eastern border of the low lying California Trough, which contains the Central Valley.

East of the Sierra Nevada, the landscape is characterized by a series of low, north-south trending mountain ranges and intervening valleys; the ranges and valleys were created by faulting that resulted in the horst and graben structures which in turn formed the Basin and Range Physiographic Province.

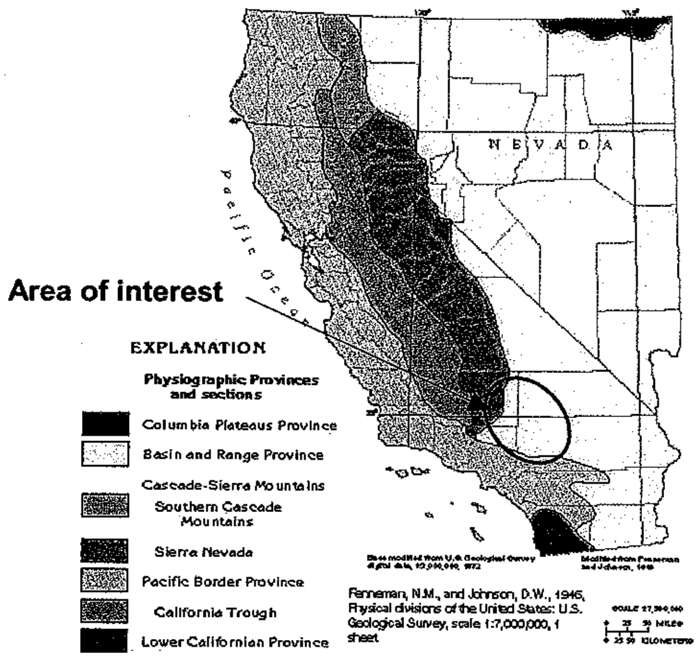


Figure A2.2 California Physiographic provinces (modified after USGS Groundwater Atlas of United States; California, Nevada).

The alternative alignment options intersect three physiographic provinces, namely: Central Valley (California Trough), Basin and Range (Mojave desert), and Pacific Border (Transverse Ranges; south of San Andreas fault alignment).

2.2 Regional structural outline

The California geographic region is situated along the active geodynamic margin between North America and North Pacific tectonic plates. The main boundary between the two plates coincides with the NNW-SSE San Andreas active fault system which separates the southern California from the rest of the north America continent.

Many other important regional active faults are present in California which determine and control the geologic development of distinct zones. The principal faults include: the NE-SW trending Garlock fault and the associated Tehachapi mountains separate the Sierra Nevada batholithic region from the Mojave desert, the complex system of San Gabriel-Santa Susana Sierra Madre faults which bound the Transverse Ranges north of Los Angeles, the San Gabriel NW-SE trending fault system which limits westward the San Gabriel mountains region, the White Wolf fault zone which intersects the southern part of the Sierra Nevada batholite.

The main faults are associated with a lateral strike slip character (San Andreas, Garlock, San Gabriel), while the minor faults are considered as compressive thrust faults (e.g., Santa Susana Sierra Madre, Pleito, and Pastoria systems) or normal type (e.g., Raymond Fault).

Practically all the above-mentioned main faults, and a significant number of minor associated faults will be crossed by the alternative alignment options. Depending on the geometric characteristics of the alignment such faults will be crossed either underground or at grade.

For the choice of the final alignment, one crucial aspect is represented by the active character of the faults. In fact, most of these faults are considered tectonically active or potentially active and seismogenetic in historic or recent (< 10,000 years B.P.) times. In this respect, California is well recognized as one of the most seismically active areas in the world. Besides, the anticipated lateral offset that could occur along major faults during earthquakes of exceptional magnitude, the design of underground structures will also have to take into consideration another important phenomenon associated with active fault zones, namely, the slow plastic slippage by which tectonic stresses are accommodated. Such movements can amount to several mm/year.

For the present study, the identification of fault zones is based on evidence from available maps (see reference documents list, Appendix 1) and on interpretation of satellite images coupled with morphologic analysis carried out on topographic maps (1:24,000 scale).

Because of their complex and long geologic history that presumably caused several lateral migrations of the principal fault plane, as well as the possible existence of multiple associated shear zones that might have been activated in different times, no attempt has been made to distinguish between the true fault planes and the associated fault affected zones, in terms of their geomechanical properties. It seems that this task might only be accomplished with the support of detailed studies and proper investigations.

Table A2.1 summarizes some characteristics of the principal faults that are considered to directly interfere with the underground sections of the studied alignments.

Table A2.1 Principal fault zones affecting the tunnels on the alternative alignments

Fault zone	Location (align., approx. chain.) (3)		Type	Attitude (dip/dip direction or strike direction)	Estimated width [m] (1)	Last seismic event year/magnitude] (2)	
S. Andreas	I-5	km 78+000	S, RH	Near vertical, NW-SE	800 - 1000	1857 (south branch)	8.0
Garlock	I-5 AV	km 70+250 km 79+350	S, LH	Near vertical, NE-SW	500 - 800	1992 (Mojave)	5.7
S. Gabriel	AV	km 177+950 km 178+200 km 178+850	S, RH	Near vertical, NW-SE	400 - 600	Quaternary	unknown
S. Susana	I-5 AV	? km 183+600 km 184+200	T	var., NW to NE	200 - 250	Late Quaternary 1971 (S. Fernando)	unknown. 6.5
Pleito	I-5	km 57+700	T	var., NNW	150 - 200	345-1465 years ago	unknown
Pastoria	I-5	km 67+000	R	var., SSE	300 - 400	unknown; probably non active	
Edison	AV	km 38+600 km 40+600	N	45-75°, NNW	100 - 200	unknown; probably non active	
Legend	S (strike-slip fault), T (thrust fault), N (normal fault), R (reverse fault); RH, LH (right-hand mov., left-hand mov.)						
Note	(1) The figures refer to the estimated width of the fault affected zone (2) From SCDEC (Southern California Earthquake Data Center http://www.scecdc.scec.org/faultmap.html) (3) Chainage onset is assumed in Bakersfield						

2.3 Lithologic and lithostratigraphic outline

The alternative, analyzed alignments traverse a variety of geologic units which can be broadly divided in three principal groups separated by unconformities: pre-Tertiary crystalline rocks; Tertiary volcanic, volcano clastic and sedimentary rocks; Quaternary sedimentary deposits.

Pre-Tertiary crystalline rocks are composed of plutonic igneous Mesozoic rocks (ranging in composition from hornblende diorite to quartz monzonite to granite) and metamorphic Paleozoic to Precambrian rocks which generally occur as isolated bodies or as interbedded layers within plutonic rocks. The two rock groups together constitute the crystalline basement upon which all later units were deposited.

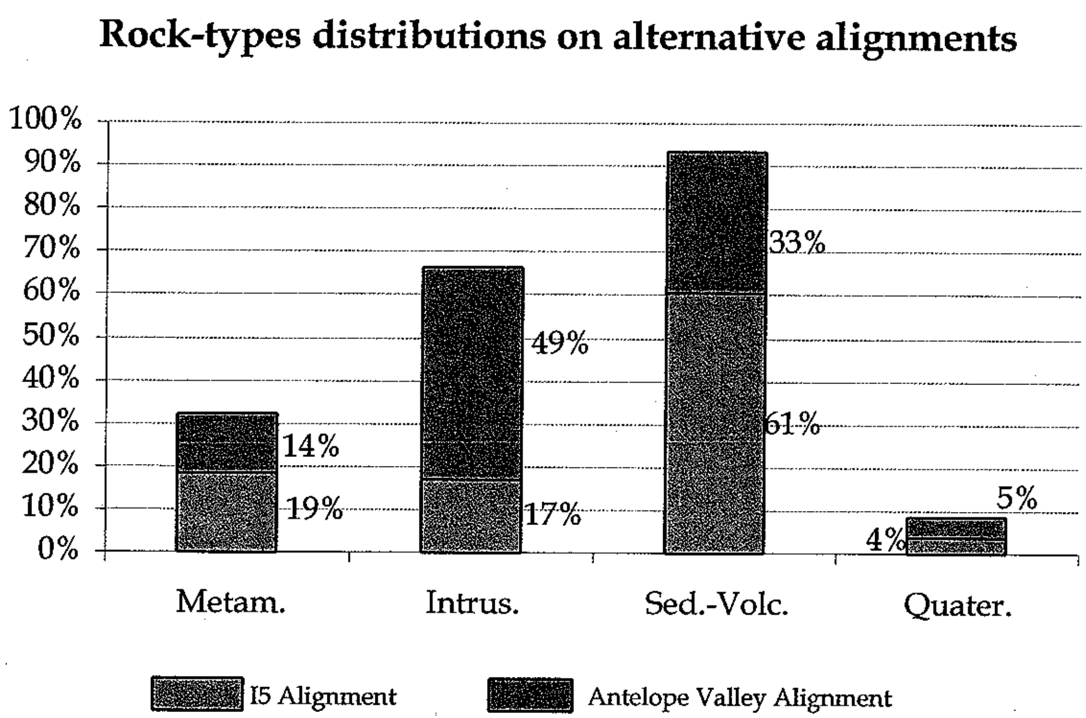
The Tertiary complex is composed of volcanic to sub-volcanic Eocene to Miocene units (rhyolite, andesite, basalt, pyroclastic rocks) and clastic flysch-like and non-marine sedimentary units (variably interbedded sandstones, siltstones, claystones and to a minor extent conglomerates).

The Quaternary deposits range from Pleistocene marine and non marine clastic deposits to fanglomeratic (i.e. sedimentary rock composed of heterogeneous unrelated materials that were originally deposited in an alluvial fan) and unlithified coarse piedmont deposits (gravel to boulder sized).

A more detailed description of the different rock-type occurrence along the alternative alignments is presented in Section 6 (Anticipated geologic conditions along alternative routes).

Figure A2.3 shows the relative distributions of different rock-types (pre-Tertiary metamorphic and intrusive rocks, Tertiary sedimentary-volcanic rocks, Quaternary deposits).

Figure A2.3 Distribution of the various rock types for the alignment options with reference to 2.5% max. grade (Metam. = metamorphic rocks, Intrus.= intrusive rocks, Sed.-Volc.= sedimentary-volcanic rocks, and Quarter.= Quaternary deposits)



Figures A2.4 gives the distribution the various rock types, in terms of both their percentage and accumulative length, on each tunnel along the I-5 alignment.

Figures A2.5 gives the distribution the various rock types, in terms of both their percentage and accumulative length, on each tunnel along the Antelope Valley alignment.